FORM PTO-1390 (REV 10-94)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
1184-6 LAM

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)
09/254333

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/DE97/01956	5 September 1997 (05.09.97)	05 September 1996 (05.09.96)

TITLE OF INVENTION "METHOD AND APPARATUS FOR DETERMINING THE PHASE AND/OR AMPLITUDE INFORMATION OF AN ELECTROMAGNETIC WAVE"

APPLICANT(S) FOR DO/EO/US
RUDOLF SCHWARTE

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. X This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ___ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing 35 U.S.C. 371.
3. X This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. X A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. X A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ___ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. X has been transmitted by the International Bureau.
   c. ___ is not required, as the application was filed in the United States Receiving Office (RO/US)

6. X A literal translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. X Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ___ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ___ have been transmitted by the International Bureau.
   c. ___ have not been made; however, the time limit for making such amendments has NOT expired.
   d. X have not been made and will not be made.

8. ___ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. X An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ___ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ___ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

12. ___ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. X A FIRST preliminary amendment.
    ___ A SECOND or SUBSEQUENT preliminary amendment.

14. ___ A substitute specification.

15. ___ A change of power of attorney and/or address letter.

16. X Other items or information:
    a. Return Receipt Postcard

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO. PCT/EP96/05143	ATTORNEY'S DOCKET NO. 250-99 (LAM)

17. X The following fees are submitted:	CALCULATIONS	PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO .....$840.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) .....$670.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) .....$760.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO .....$ 970.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) .....$ 96.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 840	
Surcharge of $130.00 for furnishing the oath or declaration later than __ 20 __ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	34 - 20 = 14	14	x $ 18.00	$ 252	
Independent Claims	3 - 3 = 0	0	x $ 78.00	$	
Multiple dependent claim(s) (if applicable)			+ $260.00	$ 260	
TOTAL OF ABOVE CALCULATIONS =				$ 1352	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$ 1352	
Processing fee of $130. for furnishing the English translation later than __ 20 __ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$ 1352	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$	
				Amount to be: refunded	$
				charged	$ 1352

a. ___ A check in the amount of $_____ to cover the above fees is enclosed.

b. X Please charge my Deposit Account No. 02-0460 in the amount of $ 1352 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. X The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 02-0460. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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IN THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US)

CONCERNING A FILING UNDER 35 U.S.C. 371

In re

Applicant	:	RUDOLF SCHWARTE
U.S. Application No.	:	(Unknown)
International Application No.	:	PCT/DE97/01956
International Filing Date	:	5 September 1997 (05.09.97)
For	:	METHOD AND APPARATUS FOR DETERMINING THE PHASE AND/OR AMPLITUDE INFORMATION OF AN ELECTROMAGNETIC WAVE
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Our Attorney/Docket Reference	:	1184-6 LAM

PRELIMINARY AMENDMENT

The specification is hereby amended by adding an Abstract. Accordingly, new page number 49 is submitted herewith to incorporate that change.

Respectfully submitted,

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ABSTRACT OF THE DISCLOSURE

A method and corresponding device for determining the phase- and/or amplitude data of an electromagnetic wave. In order to bring about the spatial depth resolution of the image data obtained, the method according to the invention comprises the following steps: an electromagnetic wave is beamed onto the surface of a photonic mixed element comprising at least one pixel, the pixel having at least two light-sensitive modulation light gates G_{am} and G_{bm} and associated accumulation gates G_a and G_b; modulation light gate voltages $U_{am}(t)$ and $U_{bm}(t)$, which are configured as $U_{am}(t) = U_o + U_m(t)$ and $U_{bm}(t) = U_o - U_m(t)$, are applied to the modulation light gates G_{am} and G_{bm}; a direct voltage, whose magnitude is at least the same as that of the total of U_o and the amplitude of the modulation voltage $U_m(t)$, is applied to the accumulation gates G_a and G_b; the charge carriers produced in the space charge region of the modulation light gates G_{am} and G_{bm} by the incident electromagnetic wave are subjected, as a function of the polarity of the modulation light gate voltages $U_{am}(t)$ and $U_{bm}(t)$, to the potential gradient of a drift field and drift to the corresponding accumulation gate G_a or G_b; and the charges q_a and q_b which have drifted to the accumulation gates G_a and G_b, respectively, are diverted. The corresponding photonic mixed element has at least one pixel which comprises at least two light-sensitive modulation light gates (G_{am}, G_{bm}) and accumulation gates (G_a, G_b) which are associated with the modulation light gates and are partitioned with respect to the incident electromagnetic wave. A plurality of photonic mixed elements can be assembled to form an array.

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Method and apparatus for determining the phase and/or amplitude information of an electromagnetic wave

The invention concerns a method and an apparatus for determining the phase and amplitude information of an electromagnetic wave.

The term phase here generally stands for phase transit time and for the designation transit time which is also used according to the respective signal shape involved.

Hereinafter reference is made to a light wave instead of an electromagnetic wave. That however does not denote a restriction only to the spectral range of visible electromagnetic waves, but is only for the purposes of simplification.

For the measurement of frequency components in terms of amplitude and phase in wide-band and high-frequency signals, the electronic measuring art and communication art frequently use phase detectors which multiply or mix the unknown signal with a sine oscillation and determine the steady component which occurs in the presence of a signal component of the same frequency by integration or low-pass filtering.

That procedure produces the correlation function of the unknown signal with the mixing signal for a given, adjustable relative phase position. By altering the mixing frequency (sweep) the unknown signal can be broken down into its spectral components. Steady component, varying amplitude and phase of the unknown frequency component of the same frequency can be determined by at least three phase positions.

The investigation of corresponding optical signals which have acquired increasing significance in the measuring and communication arts is implemented nowadays inter alia by way of wide-band photodetectors as electro-

optical transducers with subsequent electronic measurement value ascertainment, as previously described for electrical signals.

Because of the high level of expenditure involved those methods and the corresponding measurement apparatuses are usually only of a one- or two-channel nature. In the case of optical signals however very many parallel channels - in particular entire image sequences - with high frequency components frequently have to be surveyed simultaneously.

Besides the spectral modulation properties of two-dimensional light waves, an aspect of increasing interest is the rapid run of the envelope in space and time. In addition there is a wish to provide for rapidly and accurately surveying 3D-objects, for example by way of optical radar processes, which requires very fast detectors in the sub-nanosecond range, as a result of the light speed of the echo signals. At the same time they should be available as a detector array if there is desire to avoid the time-consuming operation of scanning the actively or passively bright 3D-objects.

Such a 3D-camera is proposed in DE 44 39 298 A1 which the present invention takes as its basic starting point.

Figure 10 is intended to illustrate that 3D-camera which is based on the echo transit time or phase transit time process. The HF-modulated light wave 101 which is irradiated by a modulated light transmitter 107 and 103 and reflected by the 3D-object 100 contains all the depth information in the delay in respect of the phase front. If the incident light wave is modulated once again in the reception aperture 102 with a two-dimensional, optical mixer 104 of the same frequency, which corresponds to a homodyne mixing or demodulation process, the result is a steady high-frequency interferogram.

That HF-interferogram can be recorded with a conventional CCD-camera 105 and subjected to further

processing with an image processing arrangement 106. Integration of the steady component of the mixed product in the CCD-photoelectric charge corresponds to the formation of the correlation function of the two mixing signals. The distance-related phase delays due to the echo transit times and the amplitudes can be calculated pixel-wise from three or more interferograms by virtue of different phases of the demodulating mixing frequency, for example 0°, 120° and 240° or 0°, 90°, 180° and 270°, and thus the 3D-depth image can be reconstructed.

The two-dimensional optical mixer 103 or 104 which is also referred to as a spatial light modulator or SLM comprises in that case for example a Pockel cell which has a series of serious disadvantages which are described in the literature.

Further implementation options are afforded by LCD-windows which are admittedly inexpensive but which are about a factor of 1000 too low in terms of the desired band width.

The use of a so-called microchannel plate, as is used in image amplifiers, is also expensive and costly. The gain can be modulated by modulation of the acceleration voltage which is applied to the microchannels and which influences the secondary electron emission in the microchannels.

Furthermore, the state of the art sets out a proposal for a 2D-correlator based on a CCD-photodetector array: "The Lock-In CCD-Two-Dimensional Synchronous Detection of Light" by Spirig, Seitz et. al., published in IEEE Journal of Quantum Electronics, Vol. 31, No. 9, September 1995, pages 1705 - 1708. There, a photopixel is interrogated by way of four transfer gates in order to ascertain the phase of sine-modulated light. For each sine period, a respective equidistant sample is taken with the four transfer gates, whereby the phase can be easily calculated. That procedure is too slow for the indicated problems as

the harmonic light signal is firstly integrated on during a scanning duration which significantly delimits the band width. It is only then that the desired mixing process is implemented with the stored charge being taken over as the scanning sample.

The object of the present invention is therefore that of providing a method and an apparatus for determining the phase and/or amplitude information and thus the envelope of a light wave, which permit a simpler, wider-band and less expensive correlator concept and rapid 3D-object surveying by way of a predeterminable lighting.

The above-indicated object is now attained by the method as set forth in claim 1 and by the photonic mixing element as set forth in claim 14, by the mixing element arrangement set forth in claim 20 and by the apparatus set forth in claim 23.

The principle according to the invention is based on a drift produced by the modulation photogate voltage and separation of the minority charge carriers photo-generated by the light wave in the material beneath at least two adjacent light-sensitive modulation photogates. In this case those charge carriers drift under the influence of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ applied to the modulation photogates, depending on the respective polarity or phase involved, to the accumulation gates which are biased with preferably double the dc voltage U_a and U_b. The modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ are preferably complementarily applied and are preferably composed of a bias voltage U_0 and the modulation voltage $+U_m(t)$ and $-U_m(t)$ respectively superimposed in push-pull relationship. The two modulation photogates together preferably form a square surface. A pixel with only two modulation photogates can also be referred to as a dual pixel.

This principle according to the invention presupposes the photoelectric quantum effect, caused by electromagnetic

waves. Nonetheless, reference will always be made to light waves, without this being interpreted as a limitation.

The actual mixing or multiplication process lies in the modulation voltage-dependent or phase-dependent drift of the photo-generated charge carriers to the right or to the left side of the modulation photogate ("charge swing"). In that respect the charge difference between the charge carriers which are separated in that way and collected under the accumulation gates and transmitted to the electronic reading-out system, having regard to integration in a predetermined time, represents a measurement in respect of the correlation function of the envelope of the incident modulated light signal and the modulation voltage $U_m(t)$.

At the same time the charge sum of those charge carriers which have drifted to the accumulation gates and passed on remains uninfluenced by the position of the charge swing and is available as suitable pixel intensity or as pixel grey value.

In order to determine the relative phase or time delay of the incident light wave, it is necessary - as described above - to implement three measurements in respect of the three parameters dc voltage component and ac voltage component and relative phase. Therefore, it is possible to involve a configuration of the pixel of the photonic mixing element with three light-sensitive modulation photogates which are acted upon by modulation photogate voltages which involve three different phase shifts relative to the light wave irradiated by the transmitter.

Desirably however to determine the phase of the reception signal at each pixel of the photonic mixing element from the resulting correlation amplitudes, use is made of four different measurements in regard to four different phases of the mixer signal. That provides for over-determination, by means of which the noise can be significantly reduced.

The push-pull arrangement of the modulation photogate voltages at two modulation photogates per pixel provides that two respective ones of those measurements are implemented at the same time. Therefore, for example in the case of HF-modulation, it is sufficient to implement two measurements which are respectively displaced through 90° at 0°/180° and also at 90°/270° phase difference in respect of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ respectively with respect to the phase of the radiated light in order to acquire the four different measurement values necessary.

A particularly preferred arrangement therefore is one in which the photonic mixing element respectively forming a pixel comprises four symmetrically arranged modulation photogates, wherein each two respective mutually oppositely disposed modulation photogates are acted upon with push-pull or 180°-phase-shifted modulation photogate voltages, wherein the two measurements which are respectively displaced through 90° and which have been described hereinbefore in connection with the dual pixel, with a 0°/180° and also 90°/270° phase difference of the modulation photogate voltages, are implemented simultaneously in this case. Such a pixel can also be referred to as a quadruple pixel.

Furthermore, for calibration of the phase shift of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ it is preferably possible for a part of the light waves irradiated by the transmitter to be directed as a reference directly onto at least one of a plurality of pixels of an arrangement of a plurality of photonic mixing elements. The phase and amplitude information obtained from that directly irradiated pixel can then be used for the calibration operation or can be employed for adjustment of the phase shift to a predetermined value.

Conversely, in the case of independently excited, unknown modulation of the incident light wave radiated by

an active object, by means of at least one photonic mixing element, it is possible to measure the light wave with the known high level of resolution of a lock-in amplifier. For that purpose the photonic mixing element together with a tunable modulation generator which is in place of the transmitter forms a phase-lock loop. In addition, both in lock-in amplification the phase-lock loop is used for example for HF-modulation and also the delay-lock loop is used for digital modulation.

For surveying passive objects, modulation of the irradiated light and corresponding modulation of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ respectively can be implemented in various ways. First of all it is possible to effect continuous HF-modulation, in which case the charge differences and the charge sums are read out repeatedly at intervals which can be retroactively influenced by the pixel intensity, for evaluation of the phase and amplitude information of the light wave.

An advantageous procedure is an intermittent mode of operation with pulse-form HF-modulation and lighting, for example in order for example in each case briefly to exceed an interference background lighting. In that case only the photo-generated charges are respectively integrated during the HF-pulse and then evaluated.

In determining in particular the phase or transit time information of reflected light waves, to increase the level of phase or transit time resolution, it is possible to use the HF-pulse compression process known from the radar art, with narrow correlation functions, for example the chirp procedure. In that case, both the modulation signal of the individual photonic mixing element and also the light wave of the transmitter, which lights with a predetermined phase relationship, and thus also the light wave reflected with the phase relationship being sought, is repetitively modulated with a chirp. By virtue of chirp modulation, in a suitable manner, the insertion of an adjustable delay

between the modulation photogate voltage of the photonic mixing element and the light irradiated by the transmitter provides for resolving multiple targets or suppressing troublesome multiple reflections of a lit scene.

Pseudo-noise modulation (PN-modulation) described hereinafter is available as a further form of modulation, both as base band-PN- and also HF-PN-modulation. A sampling procedure with sample-and-hold operations in the case of repetitive light signals is a special case of mixing and correlation with needle pulses. The photonic mixing element according to the invention can advantageously be used in this case also and for other uses of pulsed modulation.

The modulation modes referred to are per se all known from the state of the art.

The charges which have drifted to the accumulation gates can now be the subject of further processing in various ways. On the one hand, the photonic mixing element can be constructed using CCD-technology, in which case the charges are collected or integrated beneath the accumulation gates and then displaced in conventional manner to the CCD-read-out circuit, for example in a three-phase shift cycle, and read out by way of p- or n-diffusion.

On the other hand, the photonic mixing element can be embodied using CMOS-technology as an active pixel element with pixel-specific electronic reading-out and signal pre-processing system. In that case, in practice the reading-out circuit which is conventional in CCD-engineering is taken at both respective sides directly to the modulation photogate. In that case the accumulation gates are preferably in the form of blocked low-capacitants pn-diodes and transmit the arriving photo-generated charges preferably directly by way of the electrodes G_a and G_b to the electronic pixel reading-out and signal pre-processing system for storage and processing there.

In the latter case therefore the two charge components of the charge swing are continuously read out and can be stored practically in a reaction-free manner, for example with a charge amplifier, on a respective downstream-connected capacitor.

The state of the art provides that, before each new measurement operation, the involved, charged-up capacitors are discharged by means of electronic reset switches and that desirably the fault voltages measured in the reset condition are used for correction of the actual measurement values. That use of the pixel-wise reaction-free reading-out procedure affords the advantage that the entire dynamics of the photonic mixing element and therewith the measuring method can be considerably enhanced in comparison with implementation using CCD-technology.

In a further preferred manner it is possible to directly compute the phase and amplitude information in an electronic pixel reading-out and signal pre-processing system, preferably in the form of on-chip integration. Such an application-specific opto-electronic chip (ASOC) or such an active pixel sensor (APS) enhances the measuring rate and permits pixel-wise pre-processing of the phases and/or amplitudes.

An important advantage of the present invention is that modulation is effected simultaneously with charge generation and separation. In other words, detection and mixing take place at the same time and without additional noisy and band-limiting intermediate stages. Therefore, the time drift errors which occur inter alia in the state of the art are prevented, the charge modulation and integration operations which are separated in terms of time and space from the detection operation necessarily occur and are not to be suppressed.

A further advantage of the present invention lies in the high limit frequency of the photonic mixing element. The limit frequency of charge transfer by the push-pull

modulation voltage is comparable in terms of the maximum drift length or transfer distance, that is to say the sum length of the modulation photogates, with the limit frequency of corresponding MOS-transistors, and thus attains the GHz-range. In addition, troublesome common-mode signals are suppressed by virtue of anti-symmetrical charge carrier separation and difference formation. Each interference signal which does not correlate with the modulation signal, for example the background lighting, is suppressed in the charge difference, and that results in a high signal-to-noise ratio. Furthermore, there is only a slight time drift because of the combination of detection, mixing and charge carrier integration and difference formation on the same chip. In addition, a combination of practically all measurement functions becomes possible within a single semiconductor structure.

In comparison with the state of the art disclosed in DE 44 39 298 A1 with the use of Pockel cells as modulators, only low modulation voltages in the 1 instead of 1000 volt range are necessary. In addition, a 2D-arrangement of photonic mixing elements according to the invention ensures a large aperture on the receiver side.

In addition, no coherent or polarised light is required for determining the phase and/or amplitude information. Accordingly it is possible to use further specific properties of the incident light waves by the upstream arrangement of selective filters, for example in respect of polarisation and wavelength of the light. In addition, the arrangement affords a high level of sensitivity and a high signal-to-noise ratio by virtue of the elimination of the electronic mixers and wide-band photodetector amplifiers which are used in accordance with the state of the art.

The spectral optical band width of the light waves to be surveyed is determined by the spectral photosensitivity of the material used in the space charge zone under the

photogates, that is to say for example in the case of silicon approximately the wavelength range of 0.3 to 1.1 μm, in the case of InGaAs about 0.8 to 1.6 μm and in the case of InSb about 1 to 5.5 μm.

The photonic mixing elements can be disposed in any zero-, one- or two-dimensional arrangement, and thus afford a wide spectrum of use geometries. In that respect, several 100,000 photonic mixing elements can be operated in parallel relationship with a modulation band width of for example 10-1000 MHz, so that for example a camera shot of a 3D-scene can be implemented extremely quickly, with determination of the distance information in each pixel. The phase image $\varphi(x,y)$ or - in the case of modulated lighting - the distance image or depth image with the radius vector or voxel distance $R(x,y)$ is determined in pixel-wise manner by way of the charge differences of the charges which flow to the accumulation gates and which are read out. The corresponding charge sums afford the conventional pixel grey value $A(x,y)$. The two can be combined to give the scaled grey value image or the 3D-image $A(x,y,z)$.

In that respect, the 3D-image repetition rate is in the range of about 10 Hz to over 1000 Hz and depends on the number of photonic mixing elements used and the level of light intensity. By means of additional colour filters, it is possible to obtain the usual colour values red (x,y), green (x,y) and blue (x,y) of the distance image $R(x,y)$.

The integrated structure of mixing and charge carrier integration not least also provides for a simple structure in respect of the photonic mixing element. Finally, there is no need to involve particular expense in the reception channel for a conventional optical imaging system is sufficient for imaging of the incident, possibly reflected light wave, if a one- or two-dimensional scene and not just a point is to be recorded. The measuring apparatus can be flexibly adapted to different 3D-scenes by virtue of

synchronous zoom of the optical transmitting and receiving system.

In the case of the method according to the invention and the corresponding mixing element or an arrangement of a plurality of mixing elements, it is desirable if the pixel phase or the pixel transit time and the pixel brightness are ascertained directly by means of an active pixel sensor structure (APS) and then read out selectively or also serially preferably by way of a multiplex structure disposed on the same chip (the so-called on-chip multiplex structure). That increases the processing speed and also reduces the number of further components required.

If moreover pixel brightness is evaluated as the sum of the charges of the associated accumulation gates, as a grey value image, a particularly preferred embodiment of the invention is one which, in the case of background lighting, that is to say in the case of non-modulated lighting which is present beside the modulated lighting, eliminates by computation the charges produced by that additional lighting at the accumulation gates, by a procedure whereby the difference is formed between the grey value images which are achieved on the one hand with modulated lighting switched on and on the other hand without the modulated lighting, that is to say after the modulated light source is switched off. No correlation information is contained in that basic brightness or that base amount of the charges at the accumulation gates so that the actual correlation information appears more clearly after subtraction of that base amount.

As already mentioned it is obviously appropriate if a plurality of the mixing elements are used either in a linear array, a surface array or a spatial array. In that respect, the term "linear" array is intended to mean not only a set of mixing elements which are arranged in a straight row in side-by-side or successive relationship but generally a set of mixing elements which are arranged along

a line, wherein said line can be straight or also curved. In the case of the surface arrangements also, it is not only possible to provide planar mixing element arrangements in the form of a rectangular matrix even if that may also be preferable for practical reasons, but in principle the mixing elements can be arranged in accordance with any desired pattern and also on a curved surface, for example on the inside surface of a spherical shell. It is also possible to use arrays of the mixing elements on angled surfaces, that is to say simultaneously on two surfaces which include an angle with each other, and such arrangements are appropriate for given applications. Arrangements of that kind are embraced by the term "spatial array".

In the case of such arrays comprising a plurality of and possibly several hundred or thousand mixing elements, an advantageous and desirable configuration of the method according to the invention is one in which at least one of the pixels or mixing elements is directly irradiated with a part of the intensity-modulated electromagnetic wave serving as lighting, in which case the measurement result obtained in that way is used at said at least one pixel for calibration of the other phases and brightness results. In that respect it is desirable if such a reference pixel is acted upon by the transmitter with selectively different levels of intensity or, for the situation where a plurality of reference pixels are used, each of those pixels is acted upon by a different level of intensity. That makes it possible to avoid errors which can possibly occur by virtue of the large dynamic scope of the measurement signals.

In the case of a one- or multi-dimensional mixing element arrangement of the above-indicated kind it is desirable if the pixels are constructed using MOS-technology on a silicon substrate and can be read out with a multiplex structure, preferably with a CCD-structure.

It will be appreciated that the mixing elements

according to the invention are readily suitable for use in a digital photographic camera or video camera. For that purpose, it is only necessary to provide a suitable mixing element arrangement (for example in the form of a rectangular matrix) with integrated receiving optics, electronic evaluation system and signal processing for the difference signals, the sum signals and the associated reference signals, together with a digital memory for the grey value image computed therefrom, and the transit time or distance image. The arrangement also includes a suitable transmitter or a suitable light source which radiates a three-dimensional scene with modulated electromagnetic waves or modulated light, and transmitting optics which are suitably adjustable to the receiving optics, wherein all of those components are combined together to constitute a compact unit as a digital camera. In that respect the difference between a digital photographic camera and a digital video camera is essentially only that, in a corresponding video camera, a relatively large number of images has to be recorded and stored in correspondingly short intervals of time so that suitable devices must be provided for the storage and reproduction of corresponding image sequences.

It will be appreciated that in addition in all uses lighting or illuminating a scene can be implemented with modulated light from various spectral regions, so that the colour components or chromatic components of the images, which are obtained in that way, can be used to acquire and reconstruct complete colour images with the spatial depth information which is supplied at the same time.

For a higher band width and for example also for improved edge detection, it may be desirable to use a microlens optical system in which associated with each mixing element or pixel is a microlens optical system which reduces the incident light to the central region of the pixel so that deviations from the ideal potential

configuration at the modulation gates which occur in particular in the edge regions of the photosensitive surfaces are practically removed. In addition, out-of-focus imaging, which is produced by means of the microlens optical system, in the detector plane of the mixing elements, can ensure that the imaging of edges, the imaging of which extends randomly in the centre between the two pixel halves, does not result in the generation of difference charges at the accumulation gates, which simulate a correlation or false depth information.

Arrays with the photomixing elements according to the invention are also highly suitable for detecting and possibly also tracking predetermined one-, two- or three-dimensional structures in the field of view of the arrangement in question and with consideration additionally being given to the depth information or the object distance of the object which is being sought and which is possibly to be tracked.

In specific terms, selectively determining the amplitudes and the displacement of the X-, Y- and the time coordinate T of the modulation signals by (ΔX, ΔY, ΔT) (wherein X and Y define two linearly independent coordinates which extend on the plane of a mixing element matrix and time T means the transit time delay of the modulation signals) provides for the implementation of a three-dimensional correlation, whereby a predetermined three-dimensional object is sought in space, detected and possibly tracked.

The photomixing element according to the invention additionally also has a wide area of application in the field of optical data transmission. In that respect the photomixing element according to the invention is simply used instead of a photodiode in a conventional optical signal receiver, possibly inclusive of signal regeneration, wherein the shape of the modulation signal is adapted in the optimum manner to the signal shape and the phase of the

modulation signal is also adapted in optimum manner in a phase-lock loop to the phase position of the reception signal. In other words, the clock is obtained from the signal itself and used for optimum weighting of the reception signal, whereby the signal is separated in optimum fashion from the troublesome, noisy background. In that way, sensitivity and accuracy in respect of optical data transmission can be considerably improved in comparison with conventional photodiodes. This could in particular also permit a considerable increase in the length of the optical transmission sections without intermediate amplification and a higher number of parallel communication channels in a time, frequency and code multiplex mode.

Finally, the photomixing element according to the invention can also be used for example in optically-based position detection systems, wherein the mode of operation is in principle similar to that involved in the known GPS-system which permits very accurate determination of position by means of satellite transmitters which permit the encoded radiation of signals. In a corresponding optical position detection system the satellite transmitter which is known from the GPS-system would be replaced by a widely dispersive, modulated light source which is arranged correspondingly closer to the object whose position is to be determined, for example by means of laser diodes and an optical dispersion or scatter system, while the receiver is formed by one or more photomixing elements on the object, preferably by a plurality of photomixing elements which are oriented in various directions in order to detect the signals from light sources stationarily arranged at various points, with different modulations. In that case the encoded modulation permits a clear association of stationary light sources and the object whose position is to be determined, as well as the associated signal transit times, by means of which the position is determined.

A further use is that of a demultiplexer for optical data transmission. Encoding in the form of special modulation and the associated correlation by means of the photomixing element permits a clear association of various channels.

A further application and use of the high level of phase sensitivity of the photomixing elements according to the invention lies in the measurement of the Sagnac effect, that is to say the transit time or phase shift of light waves in rotating reference systems. For that purpose, modulated light is coupled into an optical fibre which is preferably laid in a plurality of turns and the output of the optical fibre lights one of the photomixing elements according to the invention. The modulation gates of that mixing element are modulated with the same frequency as the coupled-in light waves so that the correlation result in the form of the charge distribution at the photomixing element supplies a measurement in respect of the current frequency or phase shift. During each revolution of the reference system in which the axis of rotation is not in the plane of the turns of the optical fibre or optical waveguide, frequency and transit time and therewith also phase position change and are automatically detected by the photomixing element. It is worth noting in that respect that, with the photomixing element, such fibre gyro compass systems based on the Sagnac effect can now be embodied by means of incoherent light, which do not give rise to any problems in regard to their long-term stability as the corresponding sources of error in accordance with the state of the art, the high-frequency amplifier downstream of the optical detector and the electronic mixer, are completely eliminated.

In addition, besides absolute directional measurement which is made possible with such a system, it is also possible to effect speed measurement of a moving object by means of the photomixing element according to the

invention, for example insofar as a part of the light waves is removed in a beam splitter before being introduced into the optical waveguide and is directed onto a stationary object, in which case the light reflected by the stationary object is captured by a suitable photomixing element receiver and evaluated in the manner which has already been described on a number of occasions, here in regard to the Doppler frequency shift.

Depending on the respective meaning and significance of the additional depth information of a line or matrix image, a given number of photomixing elements can be integrated in the appropriate technology in a CCD-, CMOS- or TFA (Thin Film on ASIC)-image sensor.

Furthermore, in the use of a 3D-line or matrix camera in accordance with the invention, it may be appropriate additionally to use a conventional 2D-camera, wherein a preferably spectral allocation and feed of the active modulated illumination component to the 3D-camera, and of the other unmodulated illumination component, is preferably effected with a beam splitter.

For uses of the photomixing elements for 3D-measurement or surveying, for greater distances for which the modulated lighting is too weak, it is possible to use a combination of at least two 3D-line- or matrix cameras, in which case in accordance with the invention measurement or surveying is effected in the near region on the basis of the transit time principle and in the far region on the basis of the triangulation principle with inter alia existing background lighting.

In that case depth measurement in the near region is implemented as described hereinbefore, in this case in parallel by way of at least two cameras.

For depth measurement in the far region, the optical axes of the cameras, which are formed by way of the PMD-chip centre point, are directed onto a common point of intersection in the volume region to be measured, for

example by suitable PMD-chip displacement in the horizontal and vertical directions and in respect of the PMD-chip spacings, wherein at the same time focussing of the optical systems of the cameras are set to that distance. With suitable previous adjustment the pixel brightness values then coincide in that volume region of greatest depth sharpness.

For the detection and identification of the objects in that volume region, in the event of correspondence of the pixel amplitudes, the sum image of the photomixing elements is added by a briefly applied dc modulation voltage, in respect of the difference image, associated with the set distance data and evaluated, while the non-corresponding pixel amplitudes are removed in the difference image by a modulation voltage which is set to zero, $U_{ma} = U_{mb} = 0$.

In that way, by means of angle scanning, the 3D-scene is also measured and surveyed outside the range of the modulated transmitter lighting, wherein the necessary angles are attained both by suitable displacement of the PMD-chips and also by rotation of the individual stereo cameras and/or by pivotal movement of the entire arrangement.

The many possible uses of which only some are herein described in part in detail and in part only briefly indicated are also to be found in the following list setting forth further possible uses, the further description of which would go beyond the scope of the present application, in which respect the following list is also in no way exhaustive.

More specifically possible uses are meaningful and can be envisaged in the following areas:

- Digital 3D-photographic camera,
- Digital 3D-video camera,
- Danger area monitoring,
- Security engineering and "intelligent buildings",
- Occupant detection and identification in motor

vehicles, "intelligent air bag",

- Electronic 3D-rearview mirror,
- Recognition of the traffic situation in road traffic,
- Autonomous vehicle navigation,
- Incoherent fibre gyro and Doppler speed measurement,
- Control of autonomous transport vehicles,
- Industrial cleaning robots,
- Personal identification, authentification and checking of access authority,
- Identification of objects, for example vehicles,
- Production monitoring, material testing, 100% quality testing,
- Electronic "3D-eye" for a robot hand, robust, small, all solid state,
- Vehicle speed and distance-covered measurement, road condition detection, traffic jam,
- Track free signalling, contact wire monitoring on railways,
- Medical engineering, endoscopy,
- CDMA-engineering for optical free-space or line communication,
- Interactive 3D-communication for example in the multimedia area, and
- 3D-measurement of moving objects with a line of photomixing elements.

In that respect the following advantages of the photomixing elements of the present invention are to be emphasised (abbreviated hereinafter as "PMD" standing for "Photonic Mixer Device"):

1. PMD combines: detection, push-pull mixing and integration in a very small space of 1/100 - 1/1000 mm^2 ⇒ electro-optical correlation.

2. 2-times/4-times-PMD: substitute for 2 or 4 expensive wide-band amplifiers with high dynamics and group

transit time constancy and for 2 and 4 electronic mixers respectively.

3. The high level of electronic cross-talk sensitivity between transmitter and receiver is eliminated.

4. High level of integratability with some 100,000 parallel electro-optical modulators.

5. A PMD-3D-photographic or video camera is fully integratable, small, light, robust and flexibly adaptable by an optical zoom system for light transmitter and receiver. Measurement volumes for natural surfaces, distances of about 20 cm to 50 m with aperture angles of about 5° to 50°.

6. Extremely fast 3D-image recording in the 10 Hz - 1000 Hz-range. Sensitivity and S/N-ratio correspond to presentday CCD- and CMOS-cameras.

7. The expected depth resolution is about 0.5 mm to 50 mm depending on the respective measurement time, lighting intensity, optics involved and spacing by virtue of optimum reference.

8. Maximum band width according to respective pixel size up to the GHz-range.

9. Modulation voltages in the range of less than 1 volt.

10. No coherent, polarised or narrow-band light is required and the spectral range depends on the light-sensitive material (for example in the case of InSb up to 5.5 μm).

11. Simultaneous recording of the 3D-depth image and the 2D-grey value image, by virtue of data fusion, affords optimised evaluation of the 3D-grey value image (or 3D-colour image).

12. The read-out circuit, by virtue of intensity-dependent variation in the integration time T_i, permits an increase in the dynamics by about 8 bits (factor 256).

The invention will now be described in greater detail hereinafter by means of embodiments given by way of

example, with reference to the drawing in which:

Figure 1 shows in a) a view in cross-section of a pixel of a first embodiment of a photonic mixing element according to the invention using CCD-technology and in b) - f) the potential distribution $U_S(t)$ for the various phases or times of the two complementary modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$,

Figure 2 shows a block diagram of two linearly arranged pixels using CCD-technology including a part of an interline transfer reading device,

Figure 3 is a diagram showing the intensity distribution of the incident light and the potential patterns of the voltages $U_{sep}(t)$, $U_a(t)$, $U_{am}(t)$, $U_{bm}(t)$ and $U_b(t)$ in the case of HF-modulation,

Figure 4 is a diagram showing the characteristics of the mixing and correlation result of the photonic mixing element in the form of the averaged photo-generated charge carrier currents $\bar{i}_a$ and $\bar{i}_b$ drifting to the accumulation gates in the case of HF-modulation in dependence on the relative phase or transit time shift $\varphi_{opt}=\omega_m\tau$,

Figure 5 shows a diagram for PN-modulation, illustrating in a) the modulation signal, in b) the characteristics of the mixing and correlation result both for a dual pixel (only $\bar{i}_a$ and $\bar{i}_b$) and also for a quadruple pixel with $\bar{i}_c$ and $\bar{i}_d$ in the case of a delay in the modulation signal for the third and fourth modulation gates cm and dm of T_B and in c) the difference values $\Delta\bar{i}_{ab}+\Delta\bar{i}_{cd}=\bar{i}_a-\bar{i}_b+(\bar{i}_c-\bar{i}_d)$ and $\Delta\bar{i}_{ab}-\Delta\bar{i}_{cd}=\bar{i}_a-\bar{i}_b-(\bar{i}_c-\bar{i}_d)$ which are relevant for distance evaluation,

Figure 6 shows in a) a view in cross-section of a pixel of a second embodiment using CCD-technology of a

photonic mixing element according to the invention with a middle modulation photogate G_0 as well as the potential distributions under the modulation photogates and accumulation gates b) for a positive and c) for a negative modulation voltage $U_m(t)$,

Figure 7 shows in a) a view in cross-section of a pixel of a third embodiment of a photonic mixing element according to the invention and in b) - f) the potential distributions for the various phases, similarly to Figure 1,

Figure 8 is a plan view showing a pixel of a fourth embodiment of a photonic mixing element according to the invention with four modulation photogates and four accumulation gates, referred to as a quadruple pixel,

Figure 9 is a plan view showing a pixel of a fifth embodiment of a photonic mixing element according to the invention with four modulation photogates and four accumulation gates and a central symmetrical middle gate G_0,

Figure 10 is a diagrammatic view of an apparatus known from the state of the art for determining the phase and amplitude information of a light wave,

Figure 11 is a diagrammatic view of an apparatus according to the invention for determining the phase and amplitude information of a light wave for HF-modulation,

Figure 12 is a diagrammatic view of an apparatus according to the invention for determining the phase and amplitude information of a light wave, for example for PN-modulation or rectangular modulation,

Figure 13 shows in a) a view in cross-section of a pixel of a sixth embodiment of a photonic mixing element according to the invention with electronic pixel read-out and pre-processing system using CMOS-technology and in b) and c) the potential distribution similarly to Figure 6 for two phases or polarities of the modulation photogate voltage, and

Figure 14 is a plan view of a pixel of a sixth

embodiment of a photonic mixing element according to the invention with four modulation photogates, four accumulation gates and a middle gate G_0, of a cross-shaped configuration, preferably for digital modulation.

Figure 1a shows a view in cross-section of an individual pixel 1 of a photonic mixing element using the example of a CCD-structure. In that case the photonic mixing element, besides the pixel 1, includes the structures necessary for the voltage supply and the signal take-off operations. The outer gates G_{sep} only serve for electrically delimiting this pixel in relation to adjacent structures.

The arrangement shown in Figure 1 is formed on a p-doped silicon substrate 2. The mixing or multiplication operation of the proposed concept will firstly be considered for pure CW high-frequency modulation.

In relation to the cross-section Figure 1b - f diagrammatically shows the potential distributions for various phases of the mixing procedure. The middle modulation photogates G_{am} and G_{bm} represent the light-sensitive part and are in the inversion state. In addition to a positive bias voltage U_0 at the conductive or optically partially transparent upper cover for example of polysilicon they are operated with the superimposed push-pull voltages $U_m(t)$. That affords the modulation voltages $U_{am}(t) = U_0+U_m(t)$ and $U_{bm}(t) = U_0-U_m(t)$ respectively.

They multiplicatively cause a separation of the minority charge carriers generated by the photons of the incident light wave in the space charge zone immediately beneath the insulating layer 3, for example of silicon oxide or silicon nitride. Those charge carriers (in the example in question being electrons) drift under the influence of the modulating push-pull voltage to the closely adjacent positive accumulation gates G_a or G_b and are there integrated on while the majority charge carriers or holes flow to the ground terminal of the p-Si-substrate.

Rearward illumination is also possible.

Figure 2 shows a plan view of two pixels 1 of the photonic mixing element according to the invention including a part of an interline transfer reading apparatus 7 in the form of a 3-phase CCD shift register, at one end of which is disposed the electronic reading-out system with a diffusion junction for serial processing of the charge values obtained by correlation. After a predeterminable time T for charge accumulation under all accumulation gates of the line for example at pixel No n the charges q_a and q_b under G_a and G_b are passed by way of the respective transfer gate TG_a and TG_b to the 3-phase read-out shift register. The delimiting separation gates G_{sep} protect the correlation pixel from undesired external influences and are preferably at ground potential.

Figure 3 shows the voltage configurations associated with Figure 1. The modulation photogates G_{am} and G_{bm} are operated by means of the modulation photogate voltages shown in Figure 3, including a phase-opposition HF-modulation voltage $U_m(t)$, which are described as follows:

$$U_{am}=U_0+U_m\cos(\omega_m t) \tag{1a}$$

and

$$U_{bm}=U_0+U_m\cos(\omega_m t-180°)=U_0-U_m\cos(\omega_m t) \tag{1b}$$

Figure 1b - f clearly shows the potential distribution $U_S(s)$ in the space charge zone above the spatial extent s of a representative pixel 1 for all gates in question of that pixel in the time sequence from t_0 to t_8 for the duration of a period T_m of the HF-modulation signal. At the accumulation gates G_a and G_b a relatively high positive voltage provides for the accumulation of the photo-generated charge carriers after they have drifted either predominantly towards the left or towards the right side of the pixel 1 shown in cross-section in Figure 1, according to the polarity of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$. That operation has a particular effect when

light modulation and the modulation photogate voltage $U_{am}(t)$ involve the same frequency. Then, depending on the respective phase difference φ_{opt} there is a mean preferential direction of the charge carrier drift to the accumulation gates G_a and G_b. The associated averaged currents are described by $\bar{I}_a$ and $\bar{I}_b$.

The underlying correlation procedure can be mathematically described as follows: In the reception plane of the most general case of 2D-arrays of photonic mixing elements z = 0 and the incident modulated light wave is there generally described by $P_{opt}(x,y,t-\tau)$. Here, it is described by way of the photo-generated charge carriers with the push-pull modulation signal acting there, in general form by $U_m(x,y,t)$, approximately multiplicatively and integratively linked in terms of the charge differences in respect of the two accumulation gates. The corresponding correlation function $\varphi_{Um,Popt}(x,y,t)$ is described for example for all averaged differences of the charge carrier drifts $\Delta q_{ab}/T=\Delta\bar{I}_{ab}=\bar{I}_a-\bar{I}_b$ (with T = integration time) to the accumulation gates G_a and G_b, in the most general case, in dependence on location, as the triple convolution:

$$\varphi_{U_m \cdot P_{opt}}(x,y,\tau)=k_1 U_{am}(-x,-y,-\tau) \ast\ast\ast P_{opt}(x,y,\tau)=k_2 \Delta\bar{I}_{ab}(x,y,\tau) \qquad (2)$$

with the transit time difference $\tau = \varphi_{opt}/\omega_m$, the modulation angular frequency w_m and the constants k_1 and k_2 which are dependent on structure but which are unimportant in terms of the operating principle.

The photonic mixing element in accordance with the invention achieves that aim with a high level of positional and time resolution by virtue of the rapid separating charge transport of the photoelectrons and their push-pull storage and difference and sum evaluation. In that respect, by virtue of forming the difference of the

averaged drift currents $\Delta\bar{I}_{ab}(t)=\bar{I}_a(t)-\bar{I}_b(t)$ which are time-dependent in the case of non-stable light waves, all troublesome offset components are suppressed and at the same time the desired correlation function in respect of the light signal $P_{opt}(t-\tau)$ with the modulation voltage $U_m(t)$ is formed.

That procedure is to be described in greater detail herein. The HF-drift field caused by way of $U_{am}(t)$ and $U_{bm}(t)$ provides that the electrons drift to the respectively positive side. During for example the positive half-wave of the modulation photogate voltage $U_{am}(t) = U_0+U_m(t)$, that is to say during the negative half-wave of $U_{bm}(t) = U_0-U_m(t)$, the photo-generated charge carriers will drift to the accumulation gate G_a and are there accumulated or passed on as a charge quantity q_a (see the two upper modulation photogate voltage distributions in Figures 1b and c). Figure 3, for the situation of stable, harmonically modulated lighting, represents the optical power per pixel as:

$$P_{opt}(t-\tau) = P_0+P_m\cos(\omega t-\varphi_{opt}) \qquad (3)$$

wherein P_0 represents the mean value inclusive of the background lighting, P_m represents the modulation amplitude, ω_m represents the HF-modulation frequency, φ_{opt} represents the phase delay and $\tau = \varphi_{opt}/\omega_m$ represents the corresponding transit time delay of the incident light wave with respect to the modulation phase at G_{am}. The total photocurrent generated per pixel is:

$$i(t) = S_\lambda \cdot P_{opt}(t-\tau) = S_\lambda \cdot [P_0+P_m \cdot \cos(\omega_m t-\varphi_{opt})] \qquad (4)$$

$$i(t) = I_0+I_m \cdot \cos(\omega_m t-\varphi_{opt}) \qquad (5)$$

with the parameters $i(t) = i_a(t)+i_b(t)$, I_0 = mean value of the pixel photocurrent in accordance with P_0, I_m = alternating amplitude of the modulated photocurrent in

accordance with P_m, and S_λ = spectral sensitivity. That entire photocurrent per pixel is divided into two components, more specifically into the current $i_a(t)$ of the accumulation gate G_a and into the current $i_b(t)$ of the accumulation gate G_b. As those values are integrated - in CCD-technology under the respective accumulation gates G_a and G_b and in the case of CMOS-technology which reads out in pixel-wise manner preferably in the electronic reading system - it is sufficient hereinafter for consideration to be given to the mean values $\bar{i}_a$ and $\bar{i}_b$ of those currents. The maximum in terms of charge separation is achieved for the angle $\varphi_{opt} = 0$ and $\tau = 0$. That situation is shown in Figure 3.

Harmonic modulation affords, under the assumption of idealised conditions such as suitable modulation amplitude, negligible drift transit times, 100% modulation depth with $P_m = P_0$ for the mean photocurrents $\bar{i}_a$ and $\bar{i}_b$ respectively:

$$\bar{i}_a = \frac{I_a}{2} + \frac{I_m}{\pi}\cos(\varphi_{opt}) \tag{6}$$

$$\bar{i}_b = \frac{I_a}{2} - \frac{I_m}{\pi}\cos(\varphi_{opt}) \tag{7}$$

Figure 4 shows the configuration of these idealised mean pixel currents. They represent the opposite-phase correlation functions which result from the HF-modulated reception light and the HF-modulation photogate voltages applied at the modulation photogates G_{am} and G_{bm}. The sum thereof corresponds to I_0 of the mean pixel light power P_0. The total charge quantity which is accumulated over the time $T = N*T_m$ (that is to say over N periods T_m of the HF-modulation voltage) affords:

$$\bar{i}_a(\tau)\cdot T = q_{aT}(\tau) = \frac{I_0}{2} + const.\int_a^\tau P_{opt}(t-\tau)\cdot U_m(t)\cdot dt \tag{8}$$

with a transit time $\tau = \varphi_{opt}/\omega_m$ corresponding to the phase

delay. Hereinafter q_{aT} is only identified by q_a. The totality of the charges of the accumulation gates G_a and G_b respectively of all pixels 1 forms two locationally discrete HF-interferograms, the a-interferogram and the b-interferogram which is displaced through 180° with respect to the a-interferogram, and from them, by differencing, is formed the transit time-determined difference HF-interferogram which is being sought and which is described by equation (2).

Figure 11 is a diagrammatic view of a 3D-camera according to the invention which uses direct mixing on the basis of an array of photonic mixing elements. Compared to the 3D-camera concept known from the state of the art, which is shown in Figure 10, in Figure 11 modulation of a transmitter 4 for lighting of optically passive 3D-objects is implemented by direct modulation of the current of a laser diode. In that case modulation is produced by an HF-generator 13. For larger distances, it is advantageous for example to use a high-power laser diode array with preferably common modulation current and - for the purposes of eye safety - of different wavelengths.

A first optical system 5 forms an image of the light wave on the surface of an object 6. The light wave reflected by the object 6 is then projected through a second optical system 7 onto the surface of a photonic mixing element array 8.

The photonic mixing element array 8 is also actuated by the HF-generator 13, wherein actuation is effected for different phase shifts relative to the phase of the radiated light wave by the HF-generator 13. The signals of the photonic mixing element array 8 are finally evaluated by an evaluation unit 9, if this has not already been done on-chip.

On the basis of the measuring apparatus according to the invention, no additional optical modulator with a high aperture is needed for the proposed 3D-camera concept,

beside the photonic mixing element array according to the invention, and that affords a structure which is economically advantageous.

For the purposes of determining the pixel phase φ_{opt} from the resulting correlation amplitudes, use is made, as set forth hereinbefore, of a total of four different interferograms in the case of four different phases of the mixer signal. The four phases of the mixer signal arise in the situation where the modulation photogate voltages U_{am} and U_{bm} are switched over from the state of the phase relationship of $0°/180°$ to the state of $90°/270°$ or delayed through $90°$. That gives the two associated imaginary or quadrature components in relation to the real or in-phase components, from which the pixel phase being sought can be computed, in accordance with equation (10) described hereinafter.

That mode of operation at the same time makes it possible to eliminate troublesome offset voltages which are produced by the background brightness and by the mixing operation.

Besides the measuring operation which is described by way of example in respect of CW-modulated 3D-light waves by 2D-correlation with a modulation voltage $U_m(x,y,t)$ preferably of the same frequency in the plane of the photonic mixing element array it is possible for the measuring apparatus according to the invention also to be advantageously used with modulation signals in pulse form.

In particular pseudo-noise modulation of the light is advantageous for tasks involving high-precision transit time measurement of 3D-light waves. An embodiment by way of example for surveying or measuring optically passive 3D-objects is shown in Figure 12. Similarly to the embodiment involving harmonic modulation in Figure 11 the apparatus according to the invention has a suitable lighting device which lights the 3D-objects 6 with light which is PN(Pseudo-Noise)-modulated in intensity and the reflected

and received light is subjected to the correlation procedure with preferably the corresponding PN-modulation signal which is produced by the generator 13.

As the correlation in respect of PN-signals of that kind with increasing word length $T_W = T_B(2^N-1)$ resembles a triangular needle pulse with a half-value width equal to the bit width T_B, then for clear and complete measurement of the entire light volume or the entire space lit, a relative delay T_D between the light-modulating PN-signal and the demodulating PN-push-pull voltage $U_m(t)$ of the same signal shape at the modulation photogates must pass at least once through the entire delay range of the maximum echo transit time continuously or stepwise in T_B-steps. That purpose is served by the delay member 11 which is adjustable in respect of the delay T_D by the control and evaluation unit 9.

Figure 5a shows the modulation signal $U_m(t)$, in regard to the example of a rectangular 15 bit PN-sequence. The result of the correlation by the photonic mixing element is the averaged drift currents $\bar{I}_a$ and $\bar{I}_b$ shown in Figure 5b in relation to the relative delay τ.

In the case of the quadruple pixel described hereinafter, as shown in Figures 8, 9 and 14, the push-pull modulation photogate voltages which are applied to the modulation photogates G_{cm} and G_{dm} and which are superimposed on the bias voltage U_0 are preferably delayed by T_B with respect to the push-pull modulation photogate voltages applied to the modulation photogates G_a and G_b, that is to say $U_{cm}(t) = U_0+U_m(t-T_B)$ and $U_{dm}(t) = U_0-U_m(t-T_B)$, which results in highly advantageous amplitude and transit time measurements.

Except for a predeterminable delay T_D in respect of the modulation voltages the light intensity const.$*P_{opt}(t)$ irradiated by the transmitter 4 involves the same PN-signal structure. The reflection reaches the photonic mixing

element after the echo transit time. The correlation with the push-pull modulation voltages results, in accordance with the respective relative transit time delay τ for T_D = 0 in the ideal case without background brightness, in the case of the dual pixel in the mean pixel currents $\bar{I}_a$ and $\bar{I}_b$ shown in Figure 5b and in the case of the quadruple pixel with the stated T_B-time shift additionally in the mean pixel currents $\bar{I}_c$ and $\bar{I}_d$. That correlation characteristic firstly reveals that a plurality of object reflections can be distinguished on the same radius vector, for example for distinguishing a plurality of partially transparent objects which are disposed one behind the other or for the purposes of eliminating multiple reflections.

In addition, the sum and difference of the mean drift current differences, as shown in Figure 5c are preferably formed in succession in the case of the dual pixel and simultaneously in the case of the quadruple pixel in the respectively corresponding electronic pixel reading-out and signal pre-processing system 15. They permit highly sensitive measurements as it is only in the T_B to $2T_B$-wide measurement window that signal values that are not equal to zero appear. Evaluation of the sum makes it possible to determine the relevance of a measurement on the basis of a minimum amplitude. The difference shows a steep linear configuration in the useable T_B-wide measurement window, which permits the transit time to be determined with a high degree of resolution. The following applies for the example which is idealised here:

$$\tau = T_D + \frac{T_B}{2} - \left[\frac{\Delta\bar{I}_{ab} - \Delta\bar{I}_{cd}}{\Delta\bar{I}_{ab} + \Delta\bar{I}_{cd}}\right] * \frac{T_B}{2} \qquad (9)$$

The block diagram of a corresponding measuring apparatus for the optical measurement of 3D-objects with PN-modulation based on the proposed correlation photodetector array is characterised by a structure of

particular simplicity, as can be seen from Figure 12. In that case, besides the generator 10 and the delay member 11, the same structure as that shown in Figure 11 is involved.

In accordance with the invention, for the purposes of rapidly ascertaining distance with a relatively low level of resolution, use is also made of simple rectangular modulation of the transmitter 4 by the generator 10 with the period T and preferably the same pulse and space duration T_B. The operation of ascertaining transit time is implemented in accordance with equation (9). The level of resolution is increased stepwise by the period duration T which decreases with the factor 2, in which case the first measurement step is firstly followed by a second involving the same period but with a time shift $T_D = T/4$.

The cross-section illustrated by way of example in Figure 1 of the pixel 1 of the photonic mixing element according to the invention can be optimised in respect of its limit frequency by a suitable configuration in terms of the potential gradient caused by the push-pull modulation voltage. In that respect, Figure 6 shows an embodiment by way of example in which a middle gate G_0 is arranged between the modulation photogates G_{am} and G_{bm}, the middle gate preferably being at the bias voltage U_0 and together with the modulation photogates G_{am} and G_{bm} forming three potential stages. What is desired is a potential gradient which is as uniform as possible or a modulation drift field which is as constant as possible, and that is achieved by increasing the number of stages from two to three or even more. In the photosensitive space charge zone the degree of definition or pronouncement of the stages decreases in any case with the spacing from the insulating layer 3. That effect is used in a further embodiment in accordance with the invention, more specifically by using what is known as a "buried channel", a weakly doped n-channel which is some μm away from the insulating layer and which is

somewhat deeper in the p-substrate under the modulation photogates. The arrangement also includes a shading 12 for the accumulation gates G_a and G_b so that they are not lit by the light wave and additional charge carriers produced.

Figure 7 shows a particular configuration and connection of photonic mixing elements in which, in comparison with that in Figure 1, the two modulation photogates are respectively only separated by a common accumulation gate $G_{s,n}$, thereby achieving a higher degree of filling action. This arrangement also has a shading 12 for the accumulation gates G_a and G_b. In this case the polarity of the push-pull modulation voltages or the sequence of $G_{am,n}$ and $G_{bm,n}$ changes from pixel to pixel. That triple period of the gates is suitable at the same time for direct reading-out by virtue of operation as a three-phase shift register. A disadvantage which can be tolerated in certain applications lies in the charge distribution also to the respectively adjacent pixels, which results in an apparent pixel size increase and a lower degree of positional resolution in the direction in question.

Calculation of those interrelationships and influences shows that, in comparison with a 100% useful charge, upon evaluation of the charge differences, the central pixel considered acquires only 50% and the two adjoining pixels each acquire 25%.

To illustrate the charge distribution, Figure 7, similarly to Figure 1, shows the various phases of potential distribution for CW-modulation.

Figure 8 shows a further advantageous embodiment of the design of a pixel of a photonic mixing element which in the case of CW-modulation does not require any IQ (in-phase, quadrature-phase)-switching-over between the I- and Q-states. Instead of the above-described dual pixel, the proposal is for a quadruple pixel with the modulation photogates G_{am}, G_{bm}, G_{cm} and G_{dm} as well as the associated accumulation gates G_a, G_b, G_c and G_d, which permits

correlation simultaneously for four phase positions, as the push-pull modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$, $U_{cm}(t)$ and $U_{dm}(t)$ respectively are shifted relative to each other, in particular in the case of HF-modulation through 90°.

Therefore, in an orthogonal arrangement with respect to the described modulation photogates G_{am} with $\varphi_{am} = 0°$ and G_{bm} with $\varphi_{bm} = 180°$, there are two further modulation photogates G_{cm} with $\varphi_{cm} = 90°$ and G_{dm} with $\varphi_{dm} = 270°$ which are symmetrically integrated within the pixel and which operate on the basis of the same principle. That affords a four-phase charge accumulation with the individual charges q_a, q_b, q_c and q_d under the associated accumulation gates G_a, G_b, G_c and G_d or in the associated electronic reading-out system, wherein by means of a simple arithmetical operation the associated phase φ_{opt} is directly computed as follows:

$$\varphi_{opt}=\arctan\frac{q_c-q_d}{q_a-q_b} \qquad (10)$$

For simply determining grey values of an individual pixel, the individual charges of all accumulation gates of a pixel are summed: $q_{Pixel} = q_a+q_b+q_c+q_d$. The reading-out process in respect of the respective four charges is desirably implemented in this case by an active pixel design using CMOS-technology with pixel-wise integrated signal pre-processing.

Figure 9, like Figure 8, shows a quadruple pixel of a photonic mixing element, but with a potential gradient which is smoothed as shown in Figure 6, by means of the central square middle gate G_0 which is preferably at the potential U_0.

Figure 14, like Figure 9, shows a quadruple pixel of a photonic mixing element with a structure which is optimised for digital modulation signals. The middle gate G_0, arranged between the preferably square modulation photogates, serves in a similar manner to Figure 9 for

smoothing the potential gradient produced by the modulation photogate voltage.

Finally Figure 13 shows a further preferred embodiment of a pixel 1 which, in contrast to the above-discussed embodiments, is implemented not using CCD-technology but CMOS-technology with electronic pixel-wise reading-out and signal pre-processing system 15. In this case, the mode of operation of the modulation voltage-dependent drift of the charge carriers on the charge swing is the same as in the above-discussed embodiments. The only difference in the embodiment shown in Figure 13 is the manner of implementing further processing in respect of the charges q_a and q_b which have drifted to the accumulation gates G_a and G_b.

In the present embodiment the accumulation gates G_a and G_b are in the form of blocked pn-diodes. The positively biased accumulation gates G_a and G_b are formed by n_+-doped electrodes on a preferably weakly doped p-Si-substrate 3 in Figure 13. In what is known as the "floating-diffusion" mode of operation or in the high-resistance voltage read-out mode, as in the case of using CCD-technology, the charges q_a and q_b are integrated on the capacitances of the accumulation gates G_a and G_b and are read out in a high-resistance mode in the form of voltage values.

It is advantageously also possible to use a current read-out mode in which the photogenerated charge carriers are not integrated in the potential well but are continuously passed by way of output diffusion by way of suitable current read-out circuits which are connected to the accumulation gates G_a and G_b respectively. Those charges are then integrated for example on a respective external capacitance.

A reading-out circuit in the current read-out mode which keeps the accumulation gate voltage virtually constant by virtue of amplifier feedback advantageously ensures that, upon intensive irradiation of the pixel, the quantity of the accumulated charges q_a and q_b does not

result in a reaction on or indeed overflowing of the potential well. The dynamics of the photonic mixing element is thereby considerably improved. In this case also the above-specified technology involving a weakly doped n-channel ("buried layer") under the insulating layer of the modulation gates affords improvements, inter alia an increase in the limit frequency.

Constructing the photonic mixing element using CMOS-technology further permits the use of an active pixel design (APS) with which, at each pixel, a read-out and signal pre-processing circuit can be integrated into the photonic mixing element. That permits pre-processing of the electrical signals directly at the pixel before the signals are passed to an external circuit. In particular it is possible in that way to calculate the phase and amplitude information directly on the chip so that the measurement rate can be further enhanced.

A further configuration of the invention provides for using a preferably two-dimensional photonic mixing element array for a three-dimensional electronic object search and tracking procedure of passively or actively illuminating objects on the basis of various criteria, such as for example object shape, position, colour, polarisation, speed vector, brightness or a combination of object properties. If for example in the passage of various modulation signals (for example frequency or code alteration) in the 3D-measurement of an incident light wave which can initially be unknown, a local correlation is found by the criterion of difference drift currents not equal to zero, then that object range can thereafter be continuously measured specifically in respect of said object properties and tracked, possibly in the event of changes, by way of a regulating loop which in particular also includes image depth.

The photonic mixing element is used in various modes of operation which are set forth hereinafter.

In this respect the sum charge at the accumulation gates G_a and G_b is of less interest as it always corresponds to the total intensity of the incident light waves, q_a+q_b = const.*$P_{opt,ges}$*T with T = integration time.

The difference charge $\Delta q_{ab}=q_a-q_b=\bar{i}_a \cdot T-\bar{i}_b \cdot T$ depends on a plurality of factors and can be used in many ways for measuring the incident light wave. For that purpose, consideration is given to a basic brightness which is always present $P_0 > = P_m$ (see Figure 3a).

Optionally for example when measuring an object 6 which is lit by a transmitter 4 with modulated light the transmitter power is switched on or off and thus P_m becomes finite or equal to zero. At the same time optionally the modulation voltage $U_m(t)$ either becomes zero or it is switched to the configuration used in the transmitter and contained in the incident light, or to a voltage U_{m0} which is constant during the integration time.

Accordingly, with $P_0 \neq 0$ that gives four important modes of operation:

1.) $\Delta q_{ab} = 0$ for $P_m = 0$ and $U_m = 0$.

2.) $\Delta q_{ab} = 0$ with finite P_m and with $U_m(t)$ as an HF-modulation signal.

3.) With finite P_m and a high-frequency modulation voltage Δq_{ab} is a function of $U_m(t)$, the relative transit time shift τ and the incident light power component $P_m(t)$ which is modulated in that way.

4.) If during the integration time T there is an incident mean light intensity P_0 and a constant modulation voltage U_{m0}, then the difference charge Δq_{ab} is a function of U_{m0} and the mean light power P_0.

In the case of light waves which are not intensity-modulated, a further configuration of the invention provides that the photonic mixing element is used in accordance with the fourth case of a possible mode of operation, for example for 2D-image processing.

In that case each mixing element is actuable specifically and independently of each other, for example by pixel-wise association of a respective rapidly over-writable modulation voltage word for U_{m0} preferably by means of a RAM-component. Preferably evaluation is effected only in respect of the difference charges $_{T*\Delta\bar{i}_{ab}}$ and difference drift currents $_{\Delta\bar{i}_{ab}}$ which are approximately proportional to U_{m0}. In that case the modulation voltage U_{m0} is respectively derived from the modulation voltage word.

That means that $U_m(t)$ is no longer set periodically or quasi-periodically as in the preceding examples of use but aperiodically, for example in accordance with a predetermined image content or in accordance with the measured image content. For $U_m(t) = 0$ all difference currents are zero so that the associated difference image $D(x,y)$ also appears with the amplitude or intensity zero.

Difference image brightness can thus be specifically influenced by a variation in $U_m(x,y,t)$. In that way in accordance with the invention any light waves or images, that is to say even unmodulated ones, can be subjected to versatile image processing by way of an extremely rapidly settable weighting function $G(x,y,t) = k_1*U_m(x,y,t)$, for example by way of the above-mentioned controllable, pixel-wise associated memory cells, such as for example the above-mentioned uses for object search and tracking, but in that case without the aspect of depth information.

CLAIMS

1. A method of determining the phase and/or amplitude information of an electromagnetic wave

- in which an electromagnetic wave is radiated onto the surface of a photonic mixing element having at least one pixel, wherein the pixel has at least two light-sensitive modulation photogates G_{am} and G_{bm} and associated accumulation gates G_a and G_b,

- in which there are applied to the modulation photogates G_{am} and G_{bm} modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ which are in the form of $U_{am}(t) = U_o+U_m(t)$ and $U_{bm}(t) = U_o-U_m(t)$,

- wherein applied to the accumulation gates G_a and G_b is a dc voltage whose magnitude is at least as great as the magnitude of the sum of U_o and the amplitude of the modulation voltage $U_m(t)$,

- in which the charge carriers produced in the space charge zone of the modulation photogates G_{am} and G_{bm} by the incident electromagnetic wave are exposed to the potential gradient of a drift field in dependence on the polarity of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ and drift to the corresponding accumulation gate G_a and G_b, and

- in which the charges q_a and q_b which have drifted to the respective accumulation gates G_a and G_b are taken off.

2. A method according to claim 1

- in which an intensity-modulated electromagnetic wave is irradiated by a transmitter,

- in which the electromagnetic wave reflected by an object is radiated onto the surface of the photonic mixing element,

- in which the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ are in fixed phase relationship with the phase of the electromagnetic wave irradiated by the transmitter, and

- in which the charge carriers produced are

additionally exposed to the potential gradient of a drift field in dependence on the phase of the push-pull modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$.

3. A method according to claim 2

- in which for two different phase shifts $\Delta_{\varphi 1}$ and $\Delta_{\varphi 2}$ of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ relative to the phase of the electromagnetic wave irradiated by the transmitter the charges q_{a1} and q_{b1} as well as q_{a2} and q_{b2} are taken off and the charge differences $(q_{a1} - q_{b1})$ and $(q_{a2} - q_{b2})$ are formed, and
- in which in accordance with the equation

$$\varphi_{opt} = \frac{q_{a2} - q_{b2}}{q_{a1} - q_{b1}}$$

the pixel phase φ_{opt} of the incident electromagnetic wave is determined relative to the phase of the electromagnetic wave irradiated by the transmitter and thus the transit time of the electromagnetic wave received by the pixel is determined.

4. A method according to claim 3

- in which by means of four modulation photogates G_{am}, G_{bm}, G_{cm} and G_{dm} and four associated accumulation gates G_a, G_b, G_c and G_d, for two different phase shifts $\Delta_{\varphi 1}$ and $\Delta_{\varphi 2}$ of the modulation photogate voltages $U_{am}(t) = U_o + U_{m1}(t)$ and $U_{bm}(t) = U_o - U_{m1}(t)$ and $U_{cm}(t) = U_1 + U_{m2}(t)$ and $U_{dm}(t) = U_1 - U_{m2}(t)$ relative to the phase of the electromagnetic wave irradiated by the transmitter, at the same time the charges q_a, q_b, q_c and q_d are separated and taken off, and
- in accordance with the equation

$$\varphi_{opt} = \frac{q_c - q_d}{q_a - q_b}$$

the pixel phase φ_{opt} of the electromagnetic wave irradiated by the transmitter and therewith the transit time of the electromagnetic wave received by the pixel is determined.

5. A method according to one of the preceding claims

- in which the photonic mixing element has a plurality of pixels,

- in which at least one pixel is directly radiated with a part of the intensity-modulated electromagnetic wave from the transmitter and

- in which calibration of the phase shift between the irradiated electromagnetic wave and the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ is implemented from the phase shift measured with said pixel.

6. A method according to claim 1

- in which an electromagnetic wave with independently excited, unknown intensity modulation is radiated onto the surface of the photonic mixing element,

- in which the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ are produced by a tunable modulation generator,

- in which the charge carriers produced are additionally exposed to a potential gradient of a drift field in dependence on the phase of the push-pull modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$, and

- in which the photonic mixing element and the modulation generator form at least one phase-lock loop and the electromagnetic wave is measured in accordance with the lock-in method.

7. A method according to one of claims 1 to 6 in which a continuous or discontinuous HF-modulation, pseudo-noise modulation or chirp modulation is used as periodic modulation.

8. A method according to claim 7 in which the modulation is HF-modulation and preferably the charges q_a and q_b and possibly q_c and q_d for the phase shifts Δ_φ = 0°/180° and 90°/270° are taken off.

9. A method according to claim 1 in which a steady-state modulation is used with modulation photogate voltages $U_{am} = U_o+U_{m0}$ and $U_{bm} = U_0-U_{m0}$ with a settable modulation dc voltage U_{m0} which is constant in respect of time and with which the difference image from the difference of the charges q_a and q_b is specifically weighted.

10. A method according to one of claims 1 to 9 in which the charges q_a and q_b beneath the accumulation gates G_a and G_b are integrated and read out with a multiplex structure, preferably with a CCD-structure.

11. A method according to one of claims 1 to 9 in which the accumulation gates G_a and G_b are in the form of pn-diodes, preferably blocked low-capacitance pn-diodes and preferably using CMOS-technology, and in which the charges q_a and q_b and possibly q_c and q_d are read out directly as voltage or as current.

12. A method according to claim 11 in which the pixel phase or the pixel transit time and the pixel brightness are ascertained directly by means of an active pixel sensor structure (APS) and preferably selectively and/or serially read out by way of an on-chip multiplex structure.

13. A method according to one of claims 1 to 12 in which the pixel brightness is respectively evaluated as the sum of the charges of the associated accumulation gates as a grey value image.

14. A method according to one of claims 1 to 13 characterised in that in the case of background lighting or an external, non-modulated additional lighting, the difference of the grey value images is used as a correction parameter on the one hand when the modulated lighting is

switched on and on the other hand when the modulated lighting is switched off.

15. A method according to one of claims 1 to 14 characterised in that a plurality of separate mixing elements are used in a linear, surface or spatial array.

16. A method according to claim 15 characterised in that at least one of the pixels is directly radiated with a part of the intensity-modulated electromagnetic wave serving as lighting and that the measurement at said at least one pixel is used for calibration of the other phases and brightness results, wherein preferably the reference pixel or pixels is or are acted upon by the transmitter with different levels of intensity or levels of intensity which can be differently set.

17. A photonic mixing element

- with at least one pixel (1),
- which has at least two light-sensitive modulation photogates (G_{am}, G_{bm}) and
- accumulation gates (G_a, G_b) which are associated with the modulation photogates (G_{am}, G_{bm}) and which are shaded relative to the incident electromagnetic wave.

18. A mixing element according to claim 17 characterised in that a middle gate (G_0) is arranged between the modulation photogates (G_{am}, G_{bm}).

19. A mixing element according to claims 17 or claim 18 characterised in that the pixel (1) has four, preferably symmetrically arranged, modulation photogates (G_{am}, G_{bm}, G_{cm}, G_{dm}) and accumulation gates (G_a, G_b, G_c, G_d).

20. A mixing element according to one of claims 17 to 19 characterised in that the accumulation gates (G_a, G_b and

possibly G_c, G_d) are in the form of pn-diodes, preferably blocked, low-capacitance pn-diodes and preferably of CMOS-technology, and the charges q_a, q_b and possibly q_c, q_d can be read out directly as voltage or current.

21. A mixing element according to one of claims 17 to 20 characterised in that for the purposes of increasing the maximum modulation speed the pixel is produced using GaAs-technology, preferably of "buried channel" type (for example a buried n-channel) and with an integrated drift field.

22. A mixing element according to one of claims 17 to 21 characterised in that the pixel (1) is in the form of an active pixel sensor structure with partially pixel-related signal processing and partially line- or possibly matrix-related signal processing.

23. A mixing element according to one of claims 17 to 22 characterised in that the shading is also extended onto the edge regions of the modulation photogates.

24. A mixing element arrangement having at least two photonic mixing elements according to one of apparatus claims 17 to 23 characterised in that the photonic mixing elements are arranged in a one-dimensional, two-dimensional or three-dimensional arrangement.

25. A mixing element arrangement according to claim 24 characterised in that modulation photogates ($G_{am,n}$, $G_{am,n+1}$) and ($G_{bm,n}$, $G_{bm,n+1}$) respectively associated with two adjacently arranged, different pixels (n, n+1) respectively have a common accumulation gate (G_s) and that the modulation photogates ($G_{am,n}$, $G_{am,n+1}$) and ($G_{bm,n}$, $G_{bm,n+1}$) respectively are acted upon by the same modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$.

26. A mixing element arrangement according to claim 24 or claim 25 characterised in that there are provided devices for the direct irradiation of at least one pixel (1) as a reference pixel, by means of which a part of the intensity-modulated electromagnetic radiation emitted by the transmitter is directed onto the pixel or pixels in question.

27. A mixing element arrangement according to claim 26 characterised in that the devices for direct irradiation are equipped for a variation in respect of space and/or time of the intensity of the direct irradiation.

28. A one-dimensional or multi-dimensional mixing element arrangement according to one of claims 24 to 27 characterised in that the pixels (1) are embodied using MOS-technology on a silicon substrate (2) and can be read out with a multiplex structure, preferably with a CCD-structure.

29. A mixing element arrangement according to one of claims 24 to 28 characterised in that there is provided a microlens optical system which produces substantially for each mixing element used for image recording its own microlens by which the incident radiation is focussed onto a central region of the mixing element which can thus be reduced in size.

30. Apparatus for determining the phase information of an electromagnetic wave

- having at least one photonic mixing element according to one of apparatus claims 17 to 23,
- having a modulation generator (10, 13), and
- having a transmitter (4) whose irradiated electromagnetic wave is intensity-modulated by the modulation generator (10, 13) in predetermined manner,

- wherein the electromagnetic wave which is reflected by an object (6) is radiated onto the surface of the photonic mixing element, and
- wherein the modulation generator (10, 13) supplies the photonic mixing element with modulation voltages $U_m(t)$ which are in a predetermined phase relationship with respect to the phase of the irradiated electromagnetic wave from the transmitter.

31. Apparatus according to the preceding apparatus claim characterised in that there are provided an optical system (7) and a mixing element arrangement possibly according to one of claims 24 to 29, wherein the optical system (7) forms the image of the reflected electromagnetic wave on the surface of the mixing element or the mixing element arrangement.

32. Apparatus according to claim 30 or 31 characterised in that there are provided a mixing element arrangement with associated optical receiving system, electronic evaluation and signal processing system for the difference signals, sum signals and associated reference signals, with a digital memory for the grey value image and the transit time or distance image, a transmitter for lighting a three-dimensional scene with modulated electromagnetic waves, and with an adjustable optical transmitting system corresponding to the optical receiving system, forming a digital 3D-photographic camera in the form of a compact unit.

33. Apparatus according to claim 30 or 31 characterized in that to form a digital, three-dimensionally recording video camera, there are provided mixing element arrangement with associated optical receiving system, electronic evaluation and signal processing system for the difference signals, sum signals

and associated reference signals, with a digital memory for the grey value image and the transit time or distance image, a transmitter for lighting a three-dimensional scene with modulated electromagnetic waves, and with an adjustable optical transmitting system corresponding to the optical receiving system, wherein there are further provided memory means for the storage of digital image sequences.

34. Apparatus according to claim 32 or 33 characterised in that the transmitter is provided with devices for emitting light waves in various spectral regions for producing colour images or colour image components.

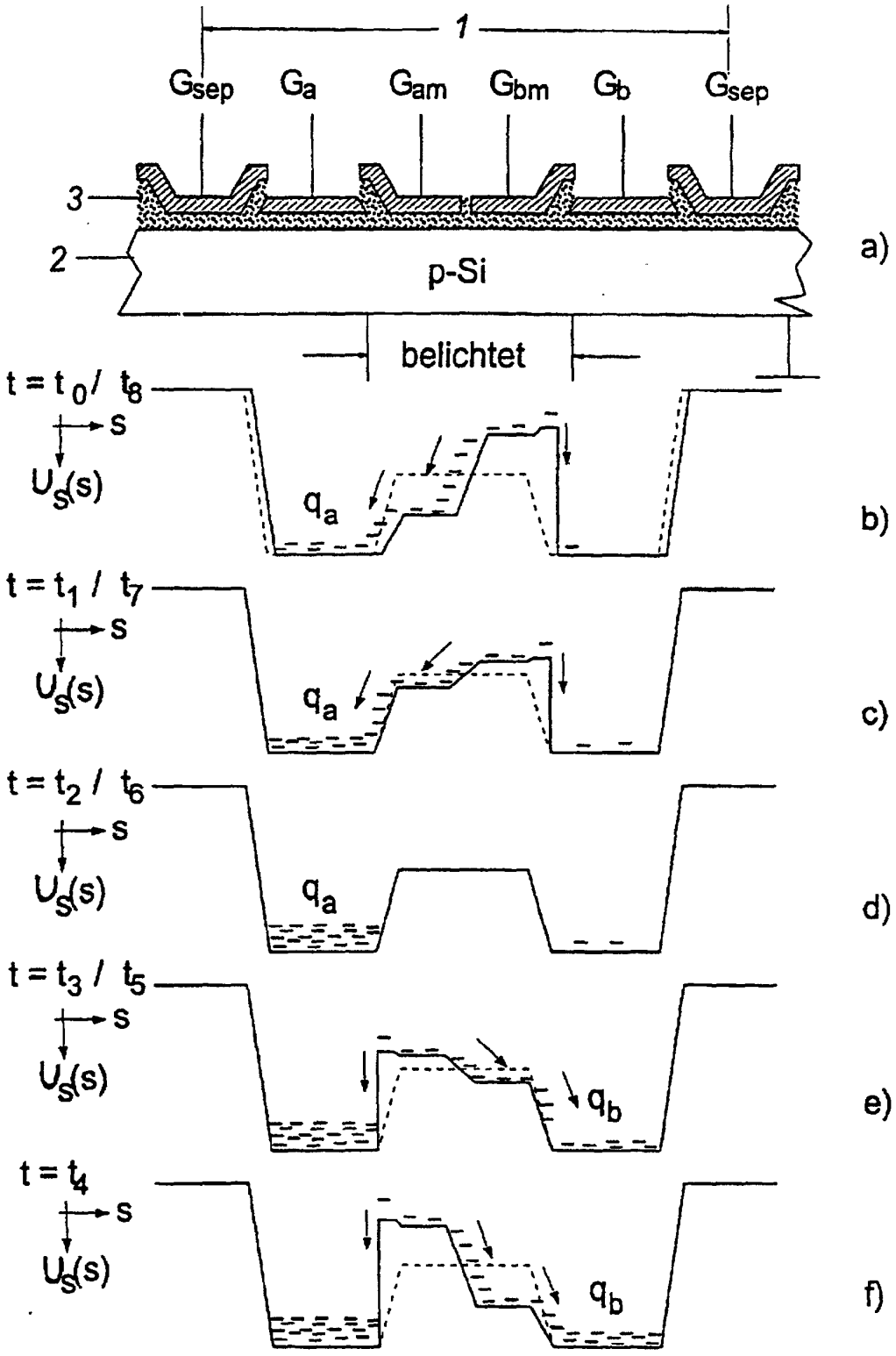
1
Gsep
Ga
Gam
Gbm
Gb
Gsep
3
2
p-Si
belichtet
a)
t = t0 / t8
s
US(s)
qa
b)
t = t1 / t7
s
US(s)
qa
c)
t = t2 / t6
s
US(s)
qa
d)
t = t3 / t5
s
US(s)
qb
e)
t = t4
s
US(s)
qb
f)

Fig. 1

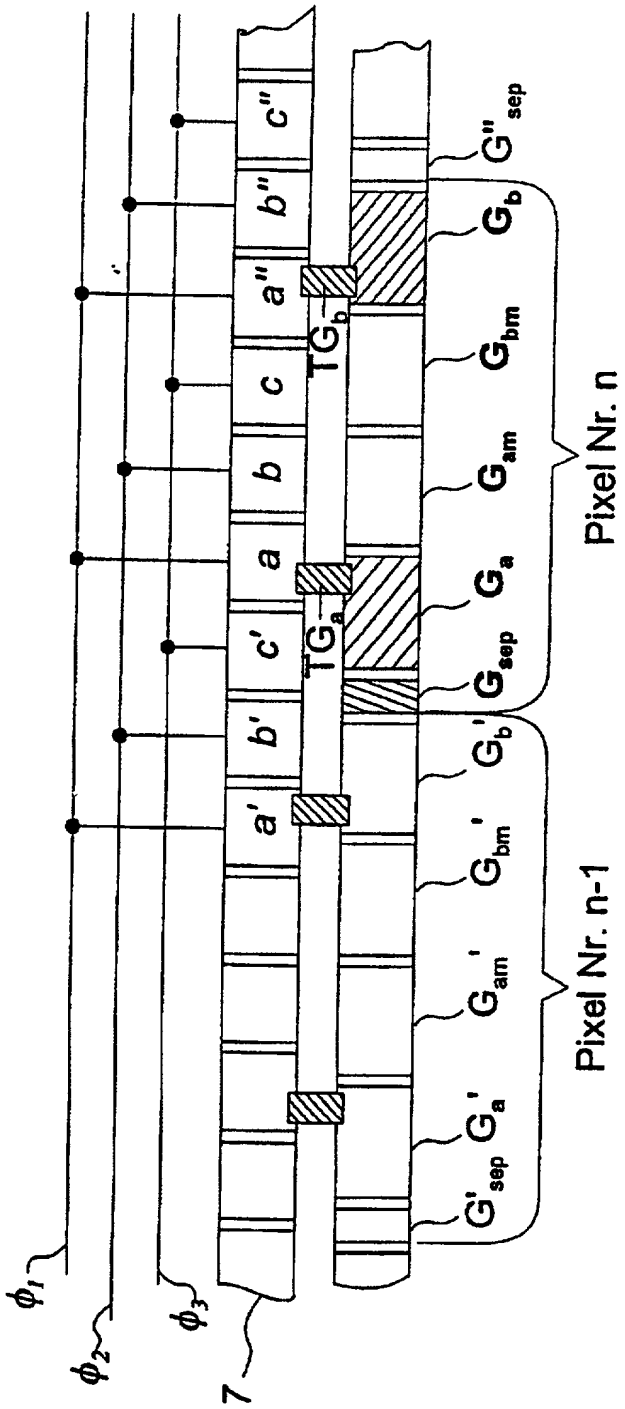
c''
b''
a''
c
b
a
c'
b'
a'
TG_b
TG_a
G''_sep
G_b
G_bm
G_am
G_a
G_sep
G'_b
G'_bm
G'_am
G'_a
G'_sep
Pixel Nr. n
Pixel Nr. n-1
φ1
φ2
φ3
7

Fig. 2

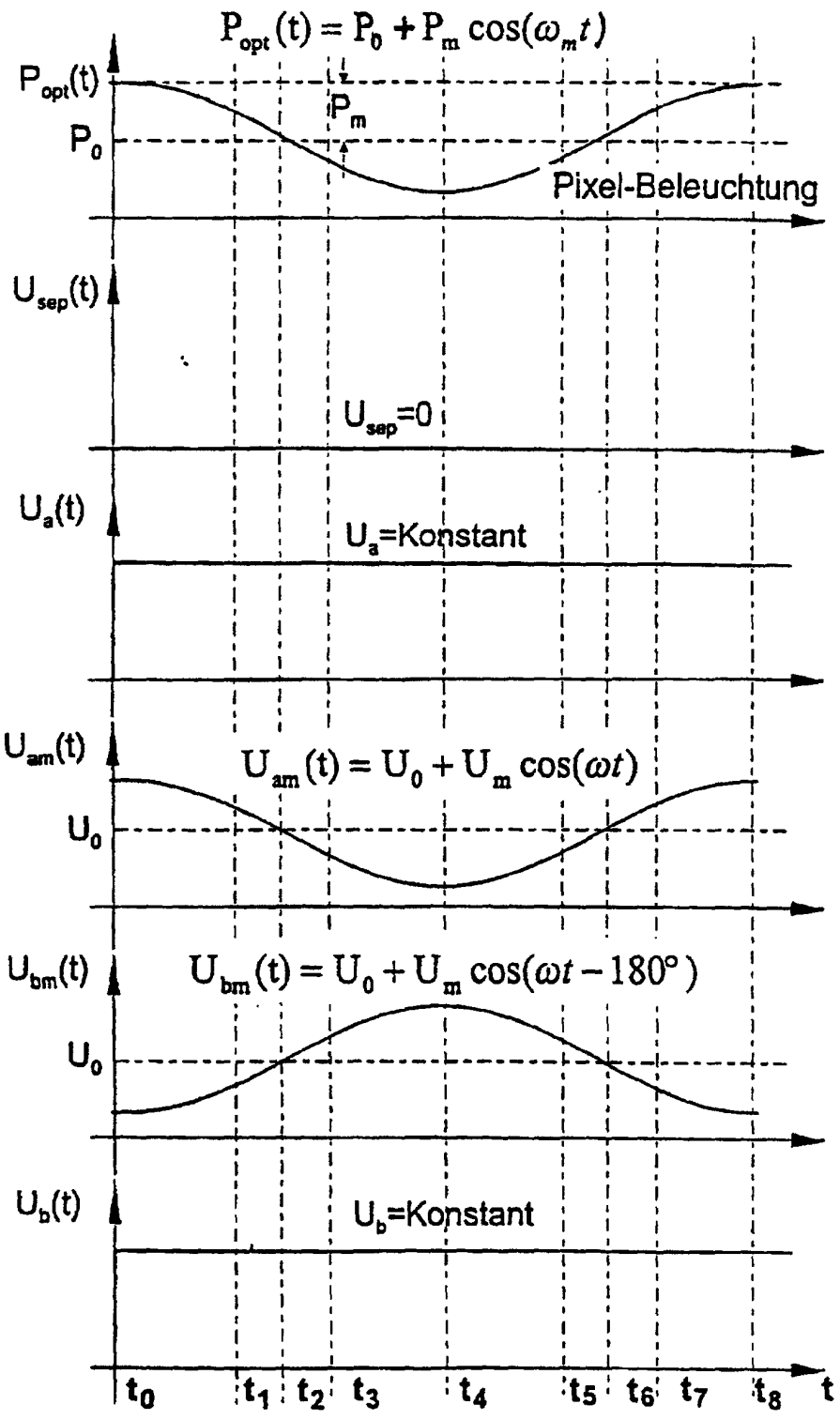
$P_{opt}(t) = P_0 + P_m \cos(\omega_m t)$
$P_{opt}(t)$
P_m
P_0
Pixel-Beleuchtung
$U_{sep}(t)$
$U_{sep}=0$
$U_a(t)$
U_a=Konstant
$U_{am}(t)$
$U_{am}(t) = U_0 + U_m \cos(\omega t)$
U_0
$U_{bm}(t)$
$U_{bm}(t) = U_0 + U_m \cos(\omega t - 180°)$
U_0
$U_b(t)$
U_b=Konstant
t_0 t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t

Fig. 3

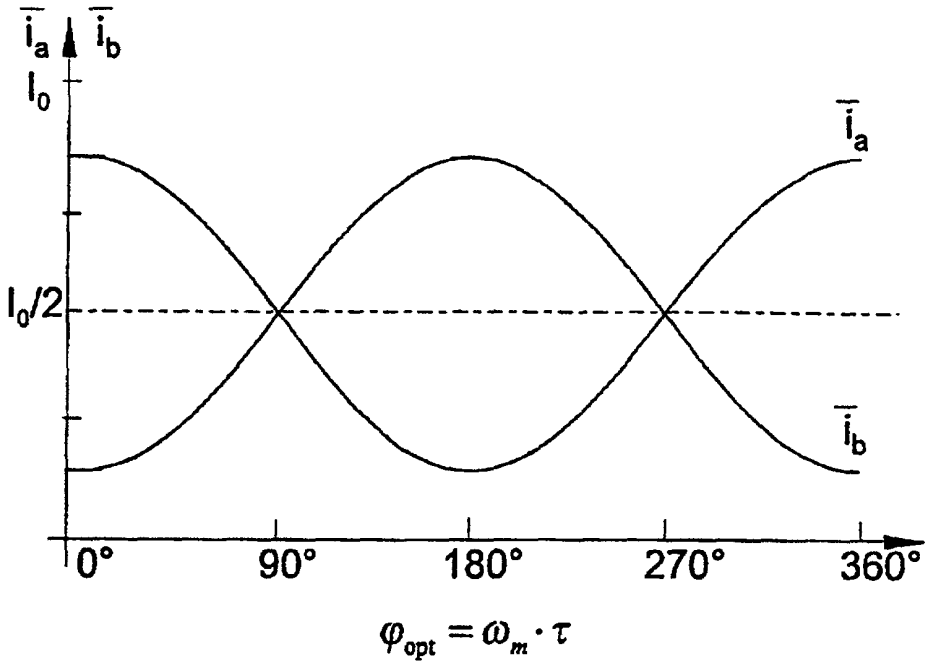
$\bar{i}_a$ $\bar{i}_b$
I_0
$I_0/2$
$\bar{i}_a$
$\bar{i}_b$
0°
90°
180°
270°
360°
$\varphi_{opt} = \omega_m \cdot \tau$

Fig. 4

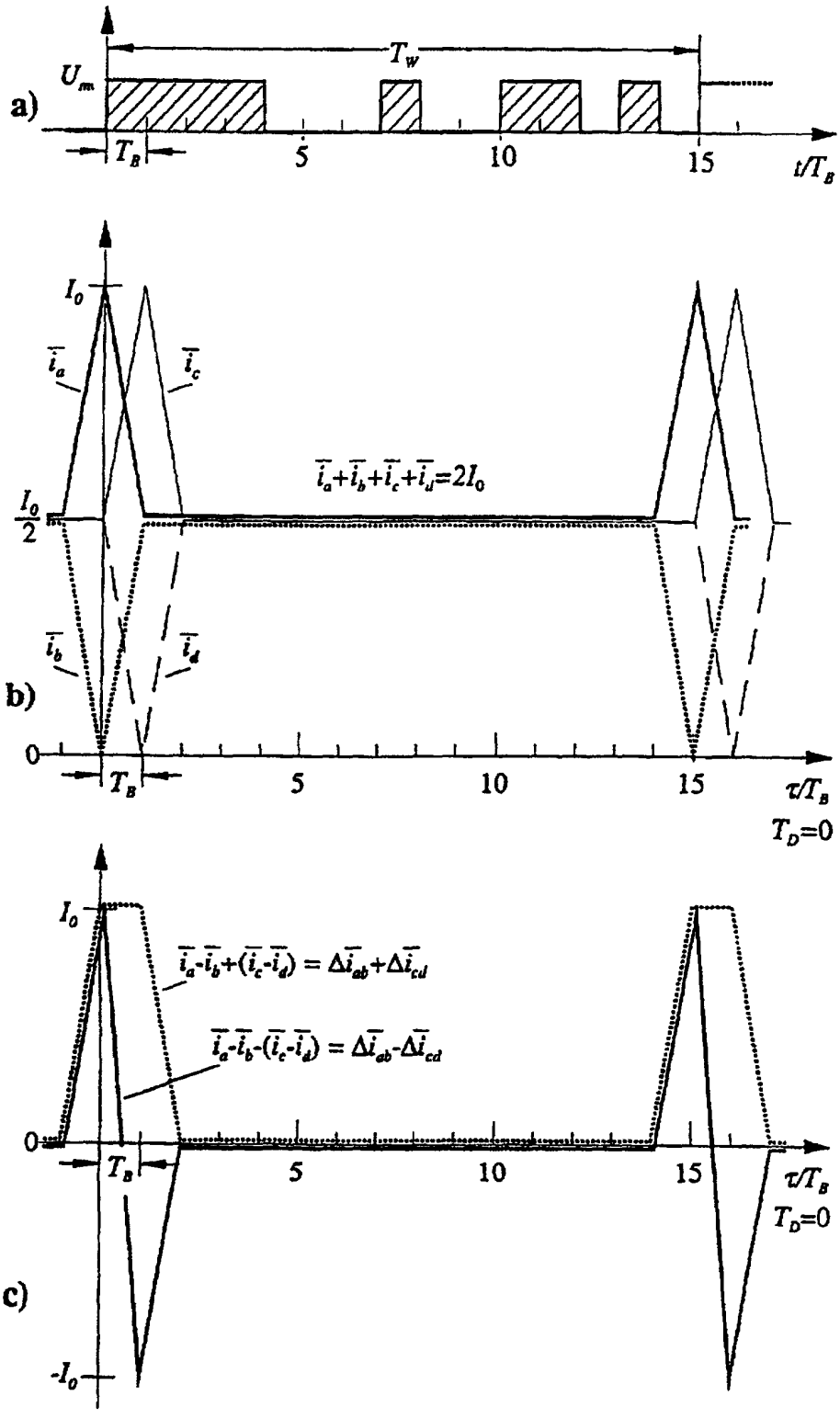
a)
U_m
T_W
T_B
5
10
15
t/T_B
b)
I_0
$\frac{I_0}{2}$
$\bar{i}_a$
$\bar{i}_c$
$\bar{i}_b$
$\bar{i}_d$
$\bar{i}_a+\bar{i}_b+\bar{i}_c+\bar{i}_d=2I_0$
0
T_B
5
10
15
τ/T_B
$T_D=0$
c)
I_0
$-I_0$
$\bar{i}_a-\bar{i}_b+(\bar{i}_c-\bar{i}_d) = \Delta\bar{i}_{ab}+\Delta\bar{i}_{cd}$
$\bar{i}_a-\bar{i}_b-(\bar{i}_c-\bar{i}_d) = \Delta\bar{i}_{ab}-\Delta\bar{i}_{cd}$
0
T_B
5
10
15
τ/T_B
$T_D=0$

Fig. 5

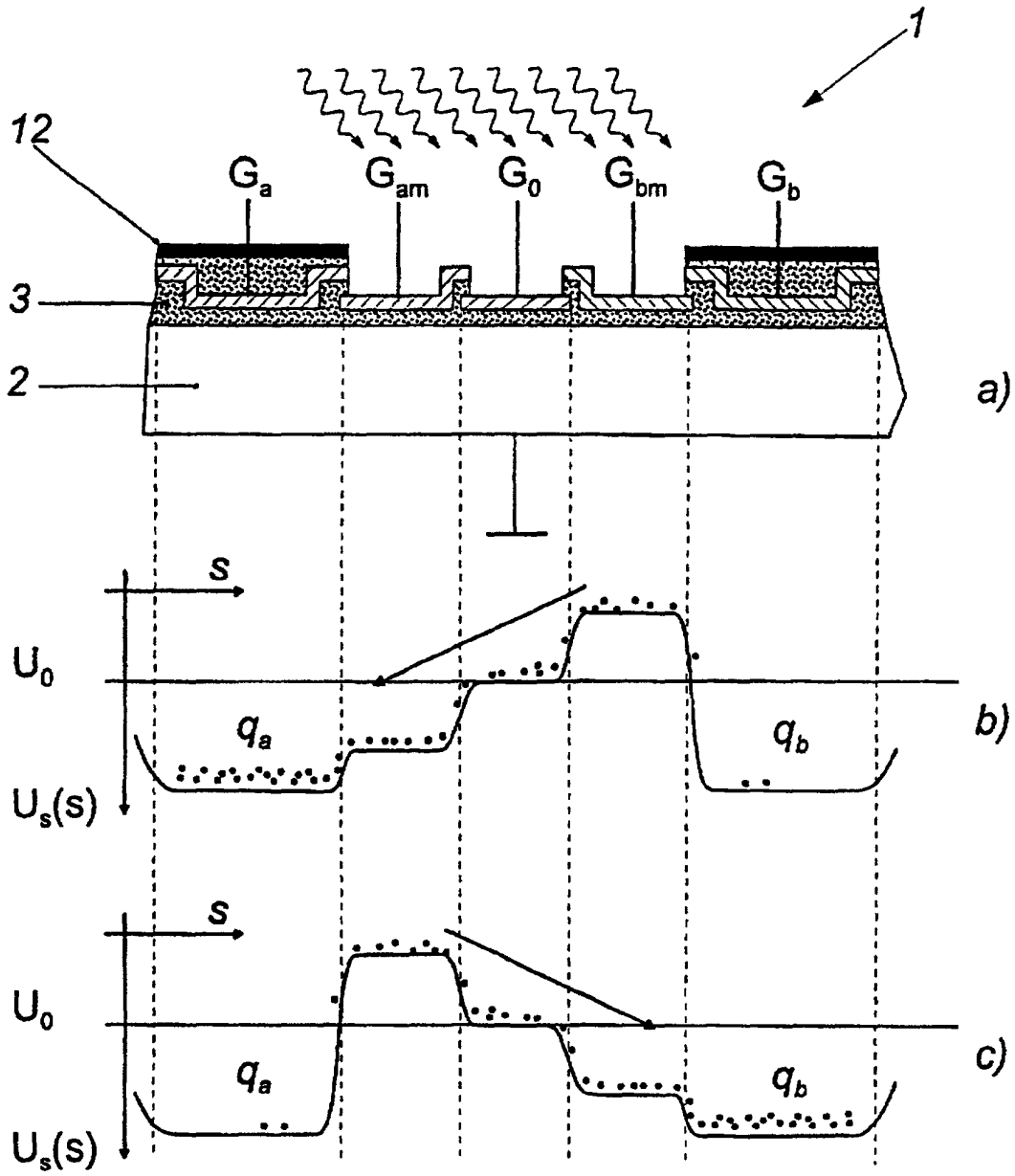

Fig. 6

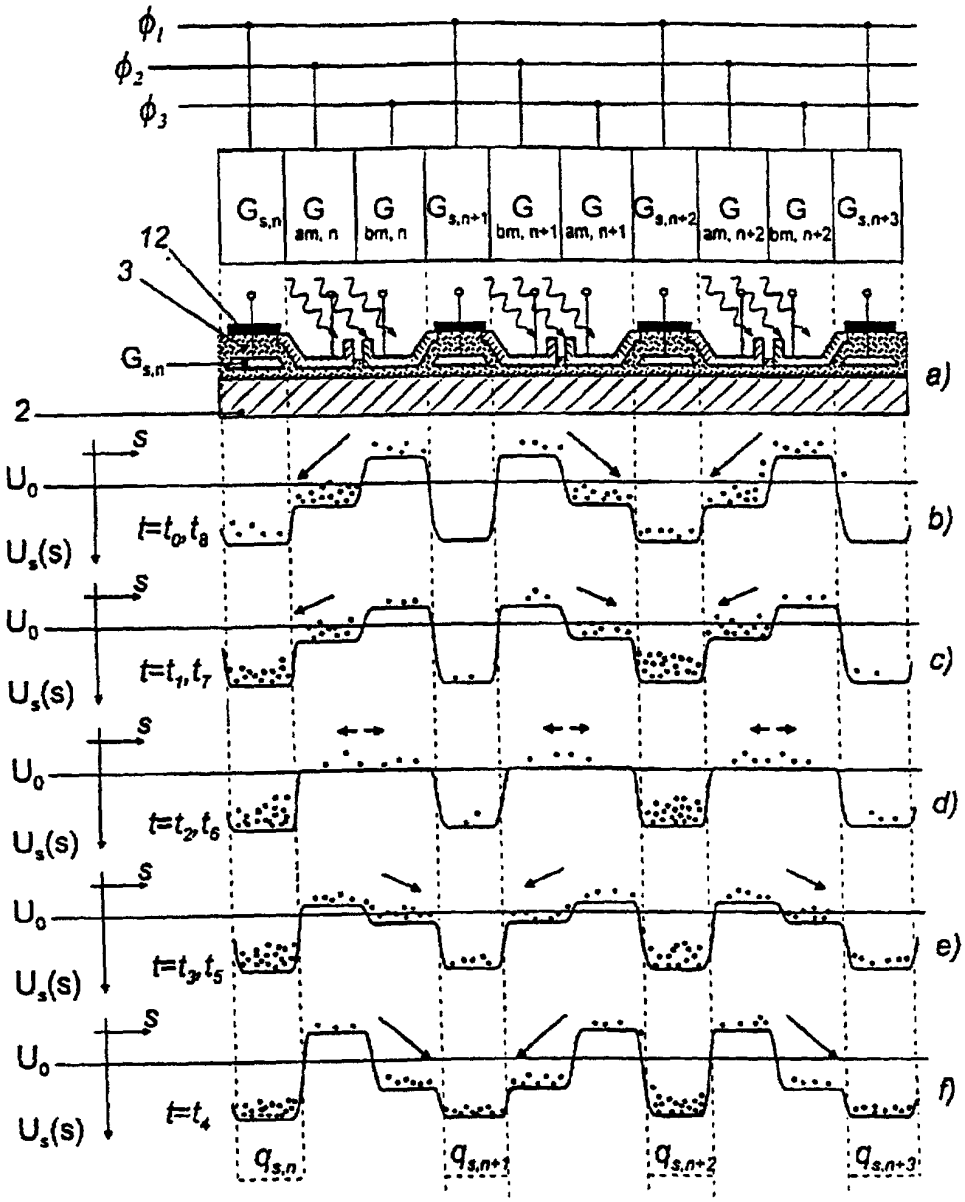
ϕ_1
ϕ_2
ϕ_3
$G_{s,n}$
G am, n
G bm, n
$G_{s,n+1}$
G bm, n+1
G am, n+1
$G_{s,n+2}$
G am, n+2
G bm, n+2
$G_{s,n+3}$
12
3
$G_{s,n}$
2
a)
s
U_0
$U_s(s)$
$t=t_0, t_8$
b)
$t=t_1, t_7$
c)
$t=t_2, t_6$
d)
$t=t_3, t_5$
e)
$t=t_4$
f)
$q_{s,n}$
$q_{s,n+1}$
$q_{s,n+2}$
$q_{s,n+3}$

Fig. 7

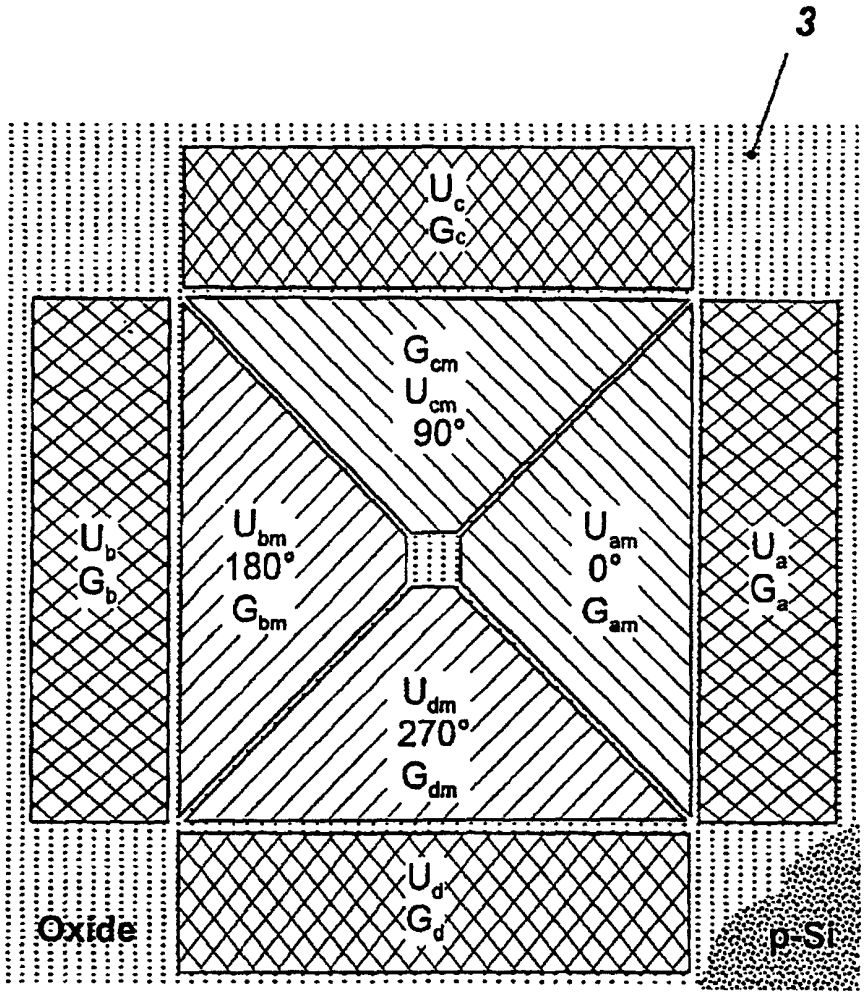
3
U_c
G_c
G_{cm}
U_{cm}
90°
U_b
G_b
U_{bm}
180°
G_{bm}
U_{am}
0°
G_{am}
U_a
G_a
U_{dm}
270°
G_{dm}
U_d
G_d
Oxide
p-Si

Fig. 8

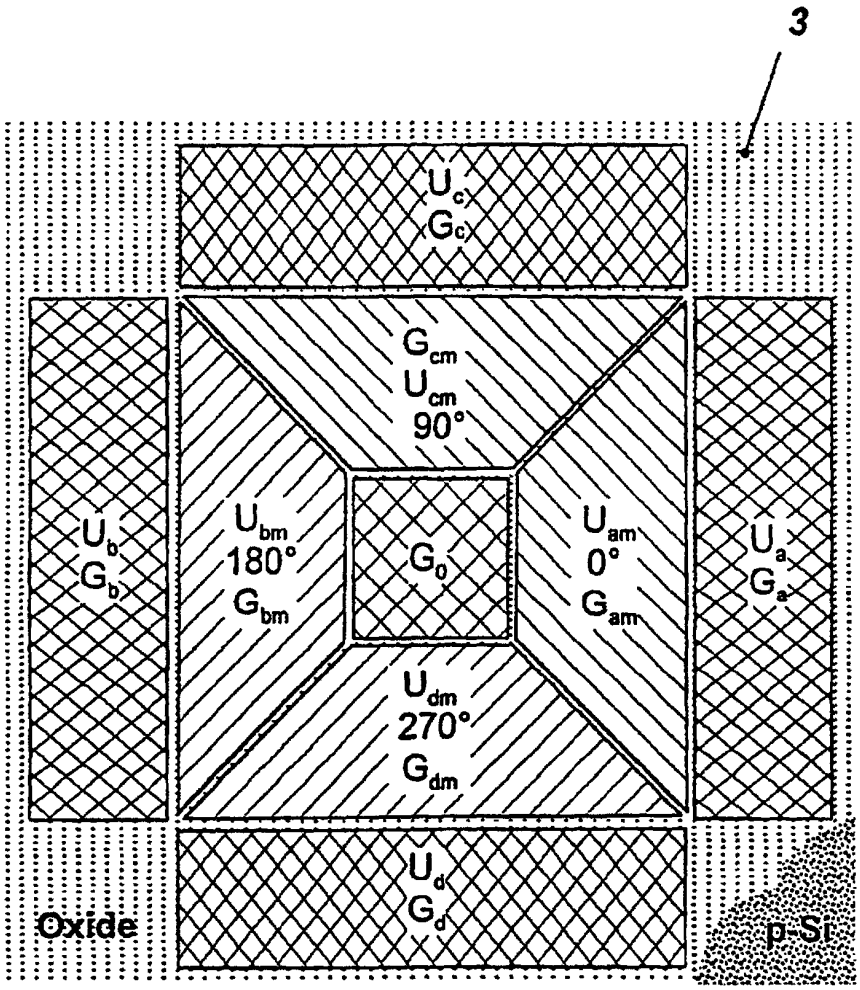
3
U_c
G_c
G_{cm}
U_{cm}
90°
U_b
G_b
U_{bm}
180°
G_{bm}
G_0
U_{am}
0°
G_{am}
U_a
G_a
U_{dm}
270°
G_{dm}
U_d
G_d
Oxide
p-Si

Fig. 9

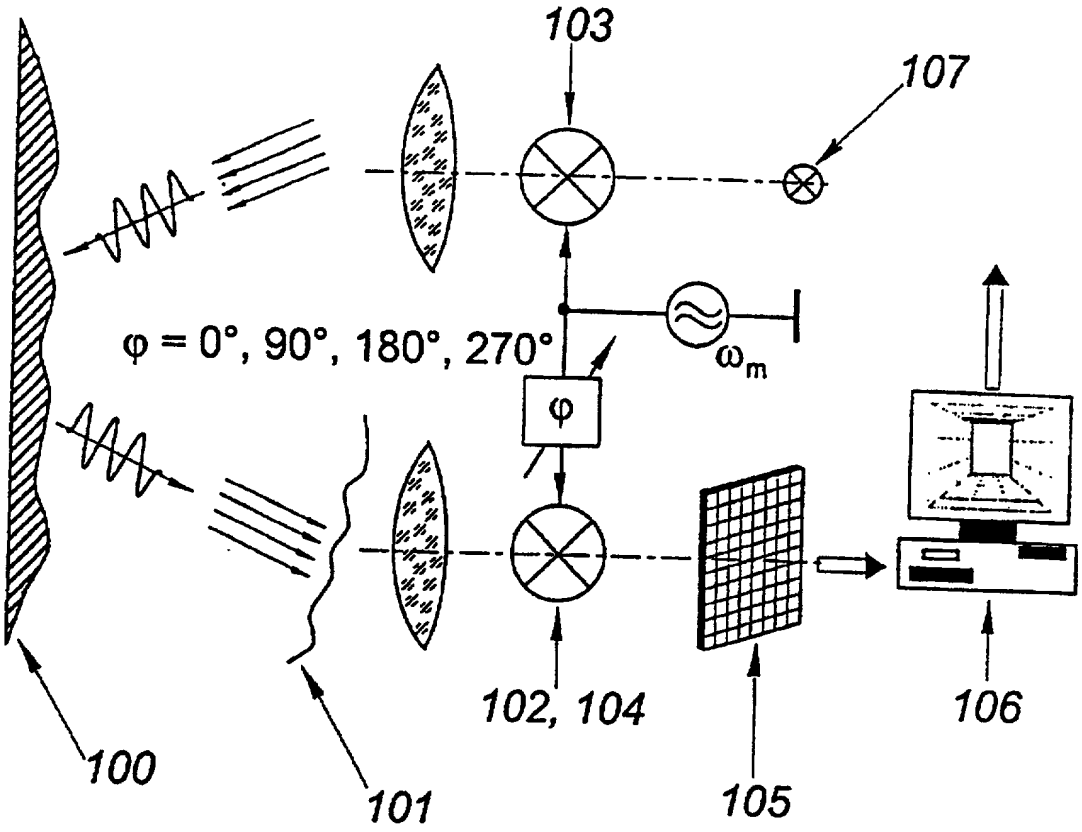

Fig. 10

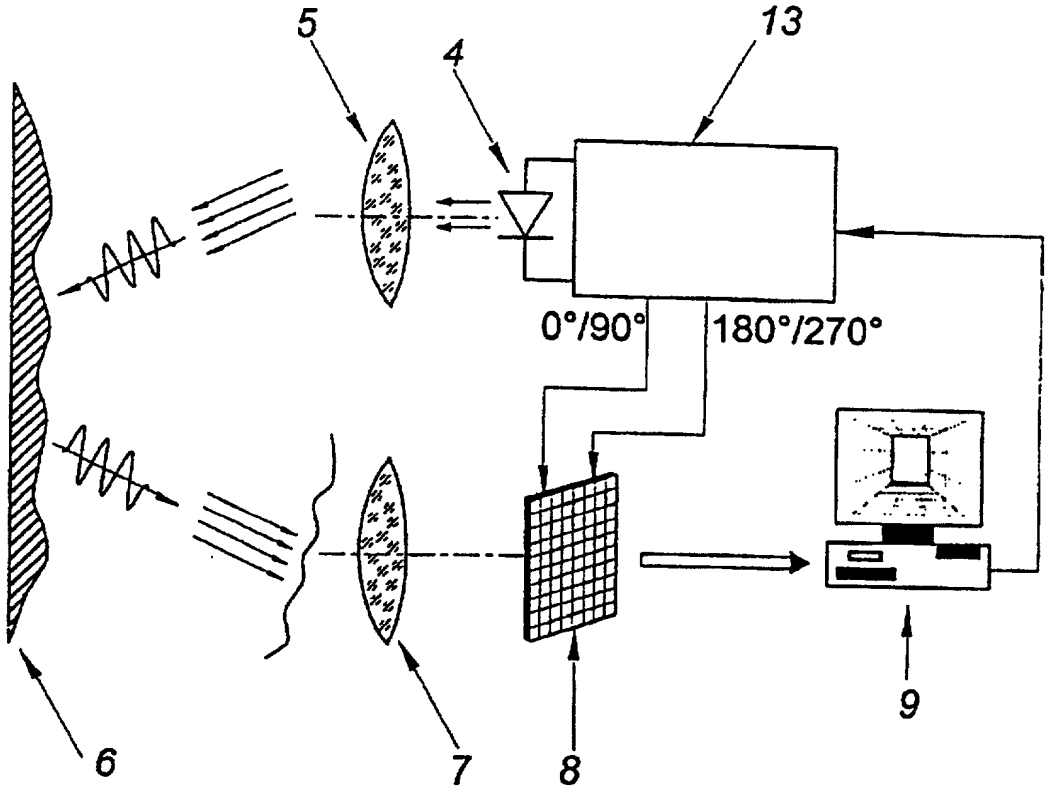

Fig. 11

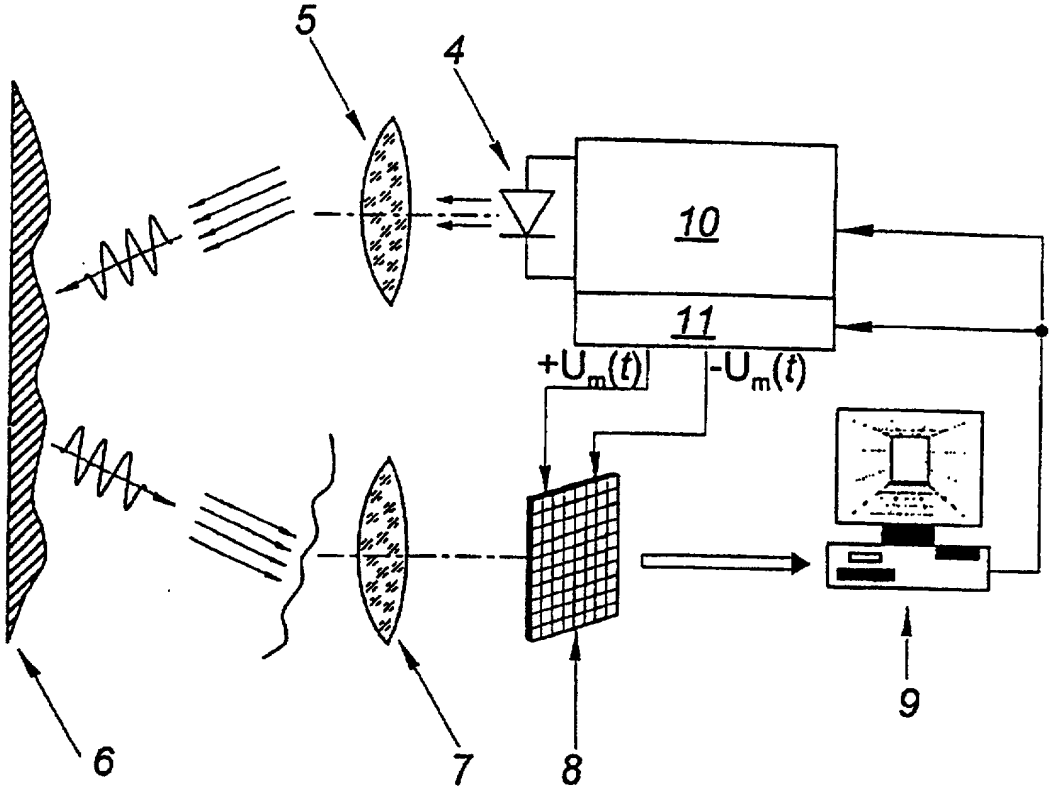

Fig. 12

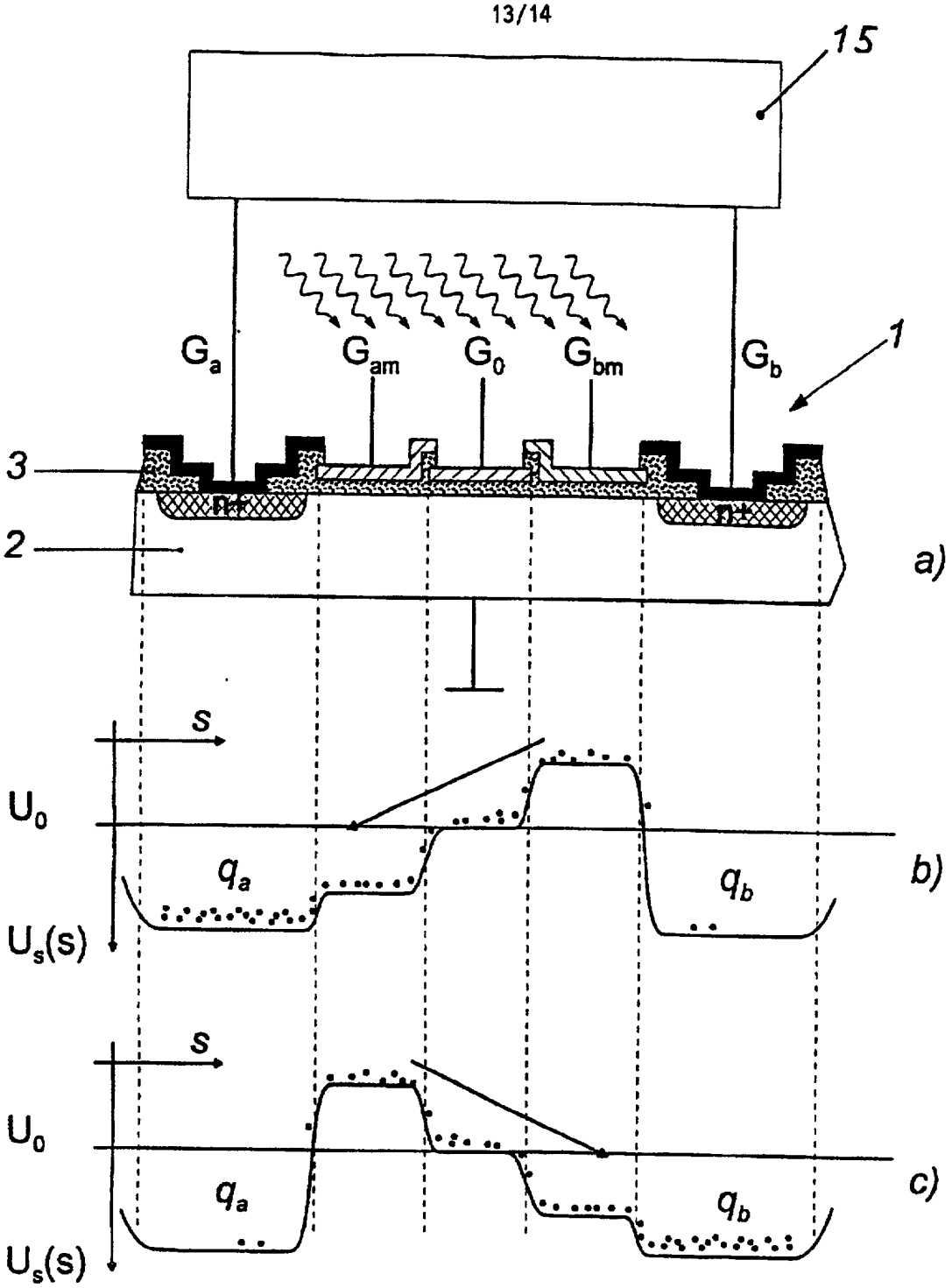

Fig. 13

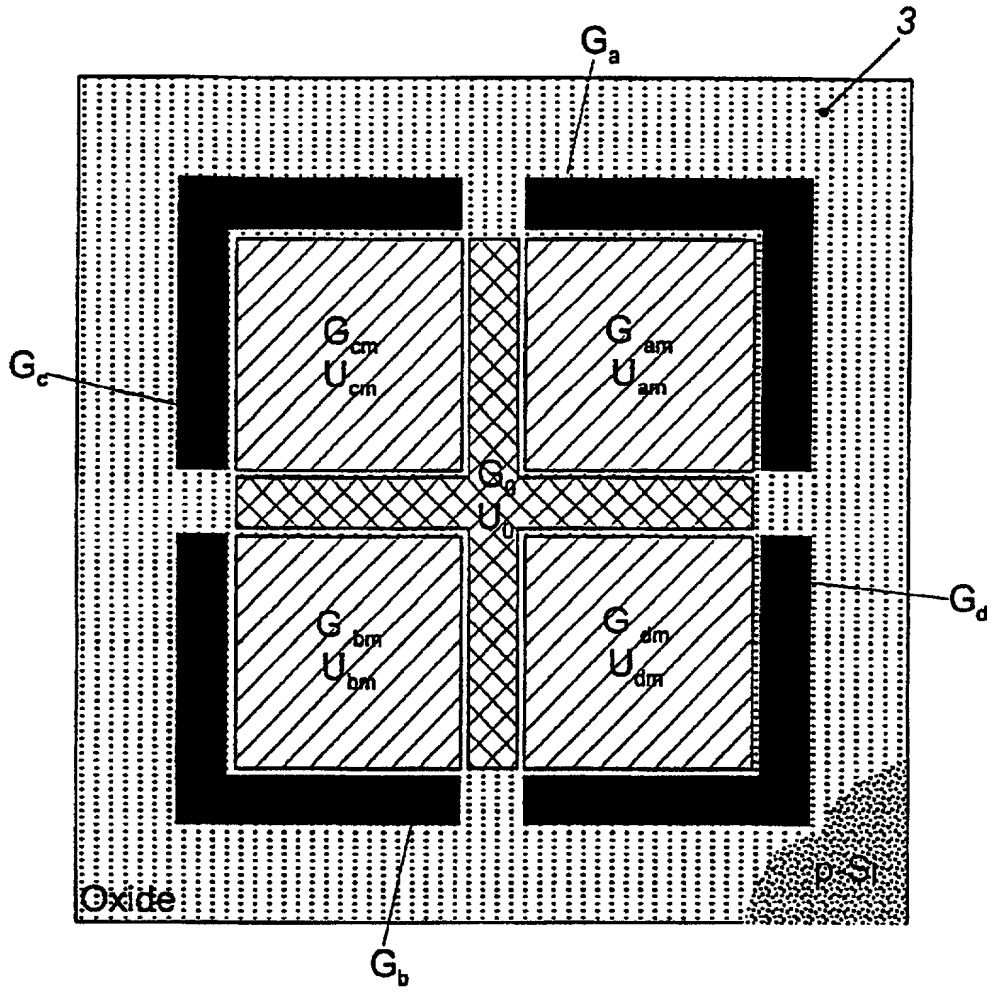

Fig. 14

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY
(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER
1184-6 LAM

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

"METHOD AND APPARATUS FOR DETERMINING THE PHASE AND/OR AMPLITUDE INFORMATION OF AN ELECTROMAGNETIC WAVE"

the specification of which (check only one item below):

___ is attached hereto.

___ was filed as United States application
Serial No. _____
on _____
and was amended
on _____ (if applicable).

_X_ was filed as PCT international application
Number PCT/DE97/01956
on 5 SEPTEMBER 1997
and was amended under PCT Article 19
on NONE (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations §1.56(a).

I hereby claim foreign priority benefit under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (If PCT indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
GERMANY	196 35 932.5	5 SEPTEMBER 1996	_X_ YES ___ NO
GERMANY	197 04 486.4	7 FEBRUARY 1997	_X_ YES ___ NO
PCT	PCT/DE97/01956	5 SEPTEMBER 1997	_X_ YES ___ NO
			___ YES ___ NO
			___ YES ___ NO

F:\CLIENT\1184\006\US-DECLA.POA

Combined Declaration for Patent Application and Power of Attorney (Continued) (Includes Reference to PCT International Applications)	ATTORNEY'S DOCKET NUMBER 1184-8 LAM

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application.

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (MARK ONE)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.				
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED *(if any)*		

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(List name and registration no.)* FRELING E. BAKER, REG. NO. 24,078; LAWRENCE A. MAXHAM, REG. NO. 24,483; PETER R. MARTINEZ, REG.NO. 42,845; CHRISTOPHER N. SEARS, REG. NO. 33,562; STEVEN J. ROBBINS, REG. NO. 40,289

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202	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY
203	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY

NO ADDITIONAL INVENTOR INFORMATION ATTACHED

I hereby declare that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any issuing thereon.

SIGNATURE OF INVENTOR 201	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
Rudolf Schwarte		
DATE: February 19nd 1998	DATE:	DATE::